THE EFFECTS OF LENGTH OF GROWING SEASON AND PLANT POPULATION DENSITY ON THE GROWTH OF LEAFY FORAGE BRASSICAS

by

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ABSTRACT OF THESIS

Experiments were carried out over three years to investigate the growth and development of leafy forage brassicas. The varieties used were Lair rape, Maris Kestrel kale and a line of Raphanobrassica developed at the Scottish Plant Breeding Station. Length of growing season was varied by utilising several sowing dates and a series of harvest dates, and in 1980 plant population density was also a treatment. A separate, smaller experiment in 1979 investigated plant population effects over a single length of growing season.

Length of growing season was found to be the most important determining factor of total yield potential. A linear relationship between total yield and length of growing season was found, which could be applied to all three varieties in all three seasons. Most of the response of total yield was in the stem fraction, with leaf and petiole yield showing less variation. Plant population density had a smaller effect on yield, most pronounced early in the season and in the lower range (13-39 m^{-2}). The stem fraction again showed the greatest response.

Raphanobrassica tended to have the greatest final leaf and petiole yields, and the lowest stem yields, whilst Lair had the lowest leaf and petiole yields and greatest stem yields. The final total yields of all three varieties were similar. Lair had the fastest early growth, whilst Maris Kestrel had a lower initial growth rate but was more persistent in growth later in the season. Raphanobrassica followed an intermediate pattern.

Further growth analysis of the 1980 results demonstrated a maximum LAI, similar for all three varieties. There was little varietal difference in LAR throughout the season, but Lair had the greatest SLA and lowest LWR, whilst Raphanobrassica had the lowest SLA and greatest LWR.

Raphanobrassica showed a tendency for flowering from sowings earlier than late June in the main experiments, and this was further investigated by two small flowering experiments. The results suggested a response to both temperature and daylength, with cold treatment and long daylength inducing full flowering, but long daylength in the absence of cold treatment only partial flowering of the crop.

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CHAPTER I

Introduction

Leafy forage crops of the genus *Brassica*, rape and kale, are grown for their shoot growth, which is used for the feeding of livestock. Their role in British agriculture is to provide part, or all, of the autumn and winter diet requirement of grazing ruminants, after grass production has ceased. Grazed and conserved grass provides up to 70% of the annual ruminant carbohydrate and protein requirement, and the deficit is made up from concentrates and forage crops (Wilkins, 1976). These crops therefore have a small, but valuable part to play in a livestock farming system. Interest in leafy brassicas reached a peak in the early 1960's, and has since declined. Recent advances in plant breeding and improved technology for growing the crops has led to a renewed interest in the crop in recent years (Cox, 1976).

The place of the leafy forage brassicas in the farming system depends both on the geographical area they are grown in, and the desired time of utilisation. They are often used as a catch crop, after a first cut of grass for conservation, or early potatoes or vining peas, and in the south after cereals, as a stubble-sown crop (MAFF, 1978). Another use is as a pioneer crop, in upland pasture improvement. In all cases their major attributes are their capacity for fast growth, and ability to produce substantial quantities of utilisable yield in the short growing season available.

In view of the importance of these crops it is surprising that the agronomic requirements for maximising dry matter production have not been clearly identified. The recent renewed activity in variety improvement through plant breeding has highlighted this lack of information (Furber, 1978). As the large amount of work on cereal breeding has shown, progress in improving the performance of a crop is greatly enhanced once the precise agronomic criteria for the comparison of

varieties has been established. This has led to the identification of the specific factors of the crop physiology which would maximise their growth potential, and, through mathematical combination and extrapolation of these factors, produced an "ideotype", or ideal model of the crop, which breeders could aim for (Donald, 1968).

The objective of this project is to identify and establish the effects of the basic agronomic factors on the leafy forage brassicas, indicate which of these factors are the most critical to growth, and establish a background for a more meaningful comparison of varieties.

CHAPTER II

Literature Review

2.1 Introduction

The literature review covers aspects of agronomy that affect the growth and use of leafy forage brassicas in the United Kingdom. For the purposes of the review the term brassica includes the fodder radish, *Raphanus sativus*, and its hybrid with kale, Raphonobrassica, together with the true brassicas, rape and kale, *Brassica napus* and *Brassica oleracea*. They all have basically the same function and usage and can thus be judged on the same criteria.

The background to each crop is summarised, followed by a survey of the effects of the length of growing season and plant population density on their yield and composition. Some consideration is then given to the factors affecting the utilisation, and thus ultimate value, of the crops.

2.2 Background and History

a) *Kale*

Kale is the most important of the leafy forage crops in the United Kingdom, in that it has by far the largest area grown. It is grown more widely in the South and West of England, and Wales, than in the North of England and Scotland. Kale is the most genetically diverse of the forage crop groupings, and is itself part of the extremely polymorphic species, *Brassica oleracea*, which also includes cabbage, cauliflower and Brussel sprouts. The kales encompass three botanic varieties within the species:

Brassica oleracea	var. *acephela*	Marrowstem kale
	var. *fimbriata*	Curly kale
	var. *fruiticosa*	Thousand-head kale

Thousand-head kales are short, many branched types, with a high proportion of leaf, but with stems that tend to be woody and indigestible. They are the hardiest of the kales, and thus the most useful for late winter feeding. Marrowstem kales are tall, thick-stemmed types, and thus have a higher proportion of stem, which is more succulent and digestible than thousand-head stems. Curly kales are short, with a "head" of very densely packed, fibrillated leaves. They are not economically important, but useful as breeding material and as a vegetable.

The cultivation of kale probably began as early as 600 BC, in Greece (Thompson, 1976). These were leafy, branching, thousand-head types. Marrowstem kales did not appear until the 19th century, in France, with unknown origin. The crop quickly spread to Germany and Denmark, and from there to Britain by 1900. It reached a peak of popularity in the UK in the early 1960's, when 160 kha were grown, but then the area began to decline. This was due partly to the animal health problems that became apparent. Kale contains an amino acid, S-methyl cysteine sulphoxide (SMCO), which has a haemolytic action, and thus if kale is fed in large quantities a condition known as "kale anaemia" can arise (Smith, 1974). A further disadvantage arose from difficulties in utilisation. Kale is usually grazed *in situ*, by strip grazing, using an electric fence. This requires a low crop, to avoid shorting of the wire. Later sowings have been used to avoid this but these also produced low establishment rates and low yields.

There was thus a large demand for a short, high-yielding and digestible kale. Marrowstem kales had high yield and digestibility, but they were too tall, and also not very winter-hardy. Difficulties in setting up a breeding programme were caused by the lack of uniformity

in the crop. Due to its neglect, great differences existed, both between and within commercial kale stocks (Sneddon, 1962). This was seldom important in the field, but for the production of special purpose varieties uniformity was essential.

At the Plant Breeding Institute, Cambridge, uniformity was obtained by selfing selections through bud-pollination, thus by-passing kale's self-incompatability system, for two generations, then making single and double crosses to restore hybrid vigour and combine desirable factors (Thompson, 1958). Later, after some problems with seed multiplication, a triple-cross method was adopted, with the additional advantage of introducing a further two inbred lines into the stock (Thompson, 1964).

The resulting hybrid, named Maris Kestrel, had a slightly lower dry matter yield than marrowstem varieties, but this was offset by a much increased digestibility, particularly of the stem, giving it comparable yields of digestible organic matter. It was shorter than marrowstems, with a higher leaf : stem ratio and better frost hardiness (Thompson and Taylor, 1970). By 1972 it was the most widely grown kale variety in the country, and demand for seed continued to exceed supply until 1977 (Taylor, 1978). This had the effect of slowing the decline in kale usage, although still not halting it.

Work continued on producing further improved triple-cross hybrids at Cambridge. In 1976 the variety Maris Merlin was provisionally added to the NIAB Recommended List, for autumn use. This was a medium height variety, taller than Maris Kestrel, but not as tall as the marrowstems (PBI, 1976). It was followed in 1977 by a similar variety, Condor (PBI, 1978), and in 1978 by Curlew and Peregrin (Taylor, 1979). Another variety, Bittern, was the result of a triple-cross involving

marrowstem kale and brussels sprouts. It had very good winter-hardiness, and was thus suitable for late winter use. Preliminary trials indicated that winter yields could be almost 20% above the mean of established varieties (Taylor, 1977).

However, a decision was made to terminate kale breeding work at Cambridge, and only Maris Kestrel, Merlin and Bittern will be commercially multiplied, with the other stock being cold-stored to provide a back-up genetic reservoir (Taylor, 1979). There is some work at the Scottish Plant Breeding Station (SPBS) on the direct selection for digestible organic matter yield in a heterogeneous outbreeding population of kale (Bradshaw, 1979), but whilst some advances have been made, the production of further, improved British kale varieties would seem to be in some doubt.

b) Rape

In the United Kingdom fodder rape is a much less popular crop than kale. The main areas of growth are Scotland, Wales and North-east and South-west England. Fodder rape is a member of the species, *Brassica napus* which contains two subspecies, *rapifera* and *oleifera*, the swedes and the rapes. As well as the fodder form of rape, annual and biennial oil-seed forms exist, which are both important crops in Northern Europe (McNaughton, 1976).

The cultivation of rape is comparatively recent. *B. napus* has been demonstrated experimentally to be an amphidiploid of *B. campestris* and *B. oleracea* (U, 1935), and it seems likely that it originally arose by natural, spontaneous hybridisation, probably several times, to give rise to the different forms. It is also possible that forage rape originated, by selection, from the oil-seed form (McNaughton, 1976).

The use of oil-seed rape was first recorded in the middle-ages, in Europe, and by the early 19th century in Britain. This was the biennial form, being used as an autumn forage, and sometimes left to yield an oil-seed crop the following year. *B. napus* is unusual in being self-fertile, whereas both its parents possess effective sporophytic incompatability systems. It is thus tolerant to inbreeding, and from the 19th century onwards progress was made through mass and line selection, with much inbreeding, leading to land races being replaced by named cultivars. The resulting fodder types were broadly classed into "Giant", "Intermediate" or "Dwarf", according to height and growth habit. As these were not distinct varieties, they often diverged markedly from type (Furber, 1978).

Recent advances have mostly been due to the introduction of distinct varieties, which have considerably improved UK standards. In the 1979/80 NIAB Recommended List, "Dwarfs" were excluded altogether, and "English Giant" had a single entry on the List. The other nine were all distinct varieties (NIAB, 1980). Otherwise the potential for improvement in rape by selective breeding is limited (Johnston, 1971). The range of variation within the crop is small, due to its recent, narrow origin. There is some scope, however, for improving disease resistance, utilisation and digestibility.

A major limitation on the use of rape is its susceptibility to club-root, a disease caused by the soil-inhabiting myxomycete, *Plasmodiophora brassicae*, which attacks the root system. It can devastate a crop by stunting and killing seedlings. It is widespread and frequent, particularly in Wales, Scotland and Western England, thriving best in damp conditions.

Four races have been identified by host specificity, and apart from New Zealand Resistant and Nevin, all rape varieties are susceptible to all races (Johnston, 1977). To avoid serious losses, a rotation of at least four years has to be employed when growing rape. Kale can also be attacked by clubroot, but it has some resistance, although of a complex and ill-defined nature (Johnston, 1977).

Nevin was derived from a cross between New Zealand Resistant rape and Wilhelmsburger swede, combining both sources of resistance, but it is a short variety, with below average yield, and also has high susceptibility to powdery mildew, *Erysiphe cruciferarum* (Johnston, 1972). The later, taller, high-yielding varieties have no resistance to clubroot, but some to mildew (NIAB, 1980). The more established varieties, Emerald and Lair, are now being rivalled by more recent introductions such as Canard and Winifred.

Several methods of introducing greater variation into rape lines have been studied. The self-compatibility of rape prevents the easy production of F_1 hybrids, as used in kale breeding. It has been shown that such hybrids exhibit useful heterosis, so a reliable method of production would be advantageous (Johnston, 1971a), and the possibility of introgressing self-incompatibility factors from *B. campestris* has been investigated. The cross of *B. campestris* x *B. napus* occurred readily, and showed potentially useful heterosis in itself (Mackay, 1973), but difficulties in maintaining a self-incompatible S-allele homozygote *B. campestris* parent, due to inbreeding depression, has prevented commercial exploitation (McNaughton *et al*, 1977). Doubling the chromosomes of the hybrid, by colchicine treatment, produced the hexaploid *B. napocampestris*. This was quite fertile, and leafy and vigorous, but a low dry matter content gave it lower dry matter yields

than the better rape varieties (McNaughton *et al*, 1977). It does, however, provide a useful method of transferring characteristics from *B. campestris* to *B. napus*, including the clubroot resistance and leafiness of Dutch and Oriental stubble turnips (Johnston, 1977).

A further approach investigated was the synthesis of *B. napus* from its two parents, *B. campestris* x *B. oleracea*, but although this cross must have occurred naturally it is extremely difficult to repeat. From a few successful crosses, several lines have been developed, but although outyielding Emerald and Lair, they suffer from the problems of low dry matter content and susceptibility to powdery mildew (McNaughton *et al*, 1977). Selection is continuing, as it does on other artificial and semi-artificial lines from SPBS and Sweden. Thus, progress is being made, but is slow. The problems of introducing and exploiting the variability of the rape crop need to be overcome, if the long-term future of the crop is to be assured.

c) Fodder radish

The history of fodder radish is more recent, and as yet it has little place in British agriculture. Nevertheless the potential of its very fast growth rate, leafiness and resistance to clubroot has attracted much attention, both in the crop itself, and also as a parent of Raphanobrassica. The species, *Raphanus sativus*, is split into four botanic varieties:

Raphanus sativus	var. *radicula*	culinary radish
	var. *niger*	large radish
	var. *mougri*	mougri radish
	var. *oleifera*	fodder radish

Fodder radish has a small proportion of root, and is grown for its foliage, mostly in Western Europe. There are two types: those that

form no "bulb", such as Rapide, Siletta and Raifort Champêtre source A, and those that do, such as Slobolt, Champêtre de l'Ardèche and Raifort Champêtre source B (McNaughton, 1973).

There is evidence that the *niger* form of radish was an important food in Egypt as early as 2700 BC (Brecker, 1962). With a confused nomenclature and the occurrence of cultivated types reverting to the wild, none of the three wild species can be identified as the originator of the cultivated form, and it is possible that all contributed. A further point of interest is the relative ease of crossing, both with several *Brassica* species, and also with *Sinapsis arvensis*, suggesting a close origin of the three genera, but firm evidence is lacking (Banga, 1976).

From Egypt, the radish spread to China by 500 BC and Japan by 700 AD. The *radicula* form is more recent, first appearing, in a long white root form, in Europe, at the end of the 16th century. Its origin is unknown, but presumably it derived from the *nigra* type. Great diversity developed in this form, both in root shape and colour. Mass selection or combined mass-pedigree-selection was practised, and this resulted in adaptions for early or late growth, ultimately producing biennial forms of the normally annual plant.

The fodder radish derived from leafier selections from oilseed forms. These were introduced into the UK from France in the early 1960's. There was much interest in their vigorous growth and leafiness, combined with disease resistance, but a tendency for flowering from all but very late sowings limited their use.

At SPBS, by mass selection from Slobolt, a strain that flowered two weeks later was developed. This was treated with colchicine, producing a tetraploid form that was even later to flower, and virtually non-flowering if sown after June. It was named Crail, and was submitted

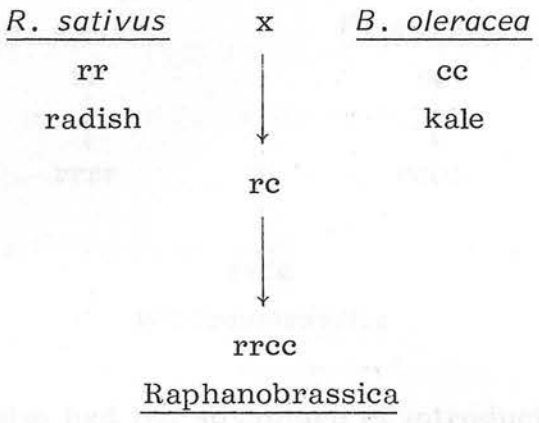
for National List trials, but failed the distinctness test due to segregation for root colour. Further selection is underway to rectify this (McNaughton, 1977). A late-flowering radish, Neris, was also selected at the Welsh Plant Breeding Station, and a tetraploid form, Rodric, was developed (Johnston, 1974). Rodric was similarly not recommended by NIAB, but Neris, along with Slobolt, forms the two listings for fodder radish on the 1979/80 Recommended List (NIAB, 1980).

Work is in progress at SPBS towards the production of a true biennial, leafy radish, thus avoiding the problems of seed production inherent in late-flowering annuals (McNaughton, 1978). In 1970 specimens of *Raphanus maritimus*, wild sea radish, were collected in the West of Scotland. These were previously reported to possess the same number of chromosomes, and to hybridise with *R. sativus*, whilst being morphologically distinct (Harberd, 1972). When they eventually flowered, in 1972, this proved to be the case. Hybrids were easily obtained by hand pollination, using *R. sativus* as the female parent (the reciprocal cross was less successful). The inter-specific hybrids were leafy, vigorous and winter-hardy. Colchicine-induced tetraploids have been back-crossed to *R. sativus*, and are being selected for leafiness and hardiness. If these hybrids are successful, the prospects for the acceptance of fodder radish as an alternative, late season crop will be much brighter. They also have potential as an improved parent for the hybrid with kale, Raphanobrassica.

d) Raphanobrassica

The history of Raphanobrassica dates from 1922, at the Moscow Agricultural Academy, USSR. Karpechenko cytologically examined *Brassica oleracea* and *Raphanus sativus* and found them to have the same number of chromosomes and, prompted by several uninvestigated reports

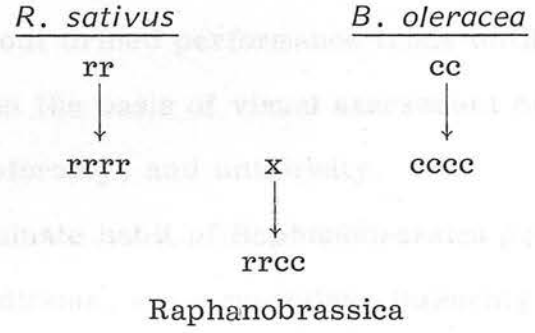
of hybrids he tried the cross himself. Surprisingly, he ended up with 123 hybrids (Karpechenko, 1924). These were a very variable set of plants, some being small and stunted and others enormous compared to their parents. Selfing and intercrossing of these hybrids resulted in some F_2 seed, which gave rise to relatively fertile plants (Karpechenko, 1927). Cytological examination showed them to be amphidiploids.



Complete chromosome pairing was found, and no segregation occurred in the F_2 or F_3 generations, so it was concluded that spontaneous doubling of the diploid hybrids had produced an intergeneric amphidiploid which was an artificial new genus, with no known wild counterparts. These first Raphanobrassica hybrids caused a great deal of interest, and detailed anatomical and cytological examinations were made (Grebinskaya, 1938; Richharia, 1937; Howard, 1938). It became the classic example of amphidiploidy, but until recently the hybrids were never considered as suitable crop plants, and no attempt was made to exploit their agricultural potential.

However, in 1967, at the Scottish Plant Breeding Station (SPBS), a programme was initiated by Dr. I.H. McNaughton with the intention of combining the best agronomic features of *B. oleracea* and *R. sativus*

and producing a superior, new fodder crop species. During 1967 and 1968 a large number of crosses were made, using as wide a range of both parent types as possible, at both a diploid and tetraploid level (McNaughton, 1973). Hybrids readily formed at both levels, but less so using autotetraploid parents. However, it was decided that this method should be used, because attempts at doubling the chromosome number of diploid hybrids met with little success.



Tetraploid method of synthesising Raphanobrassica

This method also had the advantage of introducing heterozygosity, and thus a wider genetic base, into the hybrid through the use of heterozygous tetraploid parents. The lack of success at producing Raphanobrassica through doubling the chromosomes of diploid hybrids was strange, considering that Karpechenko's plants must have arisen by spontaneous doubling. The Russian plants also had reasonable fertility, whereas the initial generations of Scottish Raphanobrassica had fertility levels as low as 0.2 seeds per siliqua.

This low fertility cannot be equated with cytological abnormalities as it was found that many euploids were completely sterile, whilst the most fertile plant was aneuploid. However, the fact that the most fertile plants were all related suggests that the genetic balance is important, so it could be that Karpechenko was just very fortunate.

The initial parents selected for the production of a commercial Raphanobrassica strain were colchicine induced tetraploids of fodder

radish cultivars, such as Slobolt, and tetraploid thousand-head and curly kales and hybrids of these two kale types (McNaughton and Ross, 1978). No marrowstem kale tetraploids were then available, but they were used in later crosses. As expected, the F_1 was very variable, 20% being chlorotic and stunted, and all had low fertility or were completely sterile. The fertility levels were gradually improved over the following generations by selecting the most productive plants in small polycross populations. Due to the low seed yields, it was not possible to carry out drilled performance trials until 1975. Until then all selection was on the basis of visual assessment of spaced plants for vigour, lack of deformity, and uniformity.

The indeterminate habit of Raphanobrassica proved to be a problem in cool, damp conditions, when secondary flowering retarded the ripening of capsules from earlier flowerings. This resulted in poor seed yield and quality at SPBS in 1976 and 1977 (McNaughton, 1978). In 1978, isolation plot seed yields were better, although site and plant variation were still present (McNaughton, 1979). The plants also lacked winter-hardiness, resulting in high losses. A more favourable climate would seem to be needed for commercially viable seed production.

Another problem with seed production is the unique nature of the seed-pods. The lower part resembles that of *Brassica*, and easily splits to release its seed, whilst the apical portion is *Raphanus*-like, and indehiscible, and thus very difficult to thresh. About 15% of the seed is in this *Raphanus* portion, so special machinery would be needed to commercially produce the seed. It may be possible to breed for better "threshability", as has been done for culinary radishes (Bonga *et al*, 1965). It is still unlikely, however, that Raphanobrassica will ever produce seed yields of the same order as rape, even if fully fertile and threshable.

The most recent Raphanobrassica hybrids have been based on marrowstem kale varieties and hybrids such as Maris Kestrel. The resulting F_1 was highly sterile, but crossing with an F_4 line, with thousand-head parentage, greatly improved the fertility. This was encouraging, as it suggests that higher fertility can easily be introgressed into earlier generations. The new hybrids appear to be more vigorous and have larger leaves, and thus a greater fodder potential than earlier material.

A notable feature of the hybrid is its resistance to clubroot, a feature inherited from its radish parent. Experiments on F_4 lines in 1972 showed them to be resistant to races that attacked all rapes (McNaughton, 1973a) and later tests at the National Vegetable Research Station, Wellesbourne, on an F_6 line showed resistance to an artificially constituted inoculum of particular virulance (McNaughton and Gowers, 1977). Testing of more recent lines has shown that not all were resistant to this inoculum, so screening and selection will be necessary to fix the highest levels of resistance (McNaughton, 1980).

Commercial exploitation of Raphanobrassica is not immediately likely, due to the problems of seed production, and also doubts about its performance as a grazing crop (Section 2.5). Work is continuing to provide a better understanding of these problems (McNaughton, 1981).

2.3 Effects of Length of Growing Season

2.3.1 Yield potential

The length of growing season, as controlled by sowing and harvest date, is the most influential factor controlling the growth, and thus yield of a crop. However, few experiments have examined this aspect of forage crops, and the main sources of variety comparisons, the

National Institute of Agricultural Botany in England and Wales, and the Scottish Agricultural Colleges, are based on trials employing a variety of both sowing and harvest dates. Trialling organisations admit that they can thus only be regarded as a general guide, and not a basis for direct crop comparisons (NIAB, 1980).

The few experiments that have included a direct comparison of varieties, and also differing lengths of growing season, demonstrate how this factor can influence such comparisons. In all cases a reduction in the length of growing season tended to reduce the final yield, but the extent of this effect was influenced by variety, and the dates of sowing and harvest employed.

Thus, in Raphanobrassica and rape comparison trials, yields of both were reduced at later sowings, late July-early August, but Raphanobrassica tended to be more affected, with the result that comparisons with rape were more favourable at earlier sowings, mid-June-July (ESCA, 1978; McNaughton and Ross, 1978; NOSCA, 1979; Harper and Compton, 1980). An exception to this trend was at NOSCA (1978) where one strain of Raphanobrassica had a better yield compared to rape from a sowing two weeks later, but this was not the case with the other strain.

The effect of varying harvest date was less clear. There was a general tendency for an increase in yield at later harvests, but delaying harvest past the end of November caused a decrease in yield (ESCA, 1978; NOSCA, 1979). Both Raphanobrassica and rape were similarly affected.

In an experiment in Wales involving a range of both sowing and harvest dates, radish was compared with rape. A much later range of sowing dates was employed, early-late August, producing low yields,

with changes in sowing date having a greater relative effect on final yield than changes in harvest date (Johnston, 1963). Another, concurrent trial demonstrated that the yield advantage of radish found in such conditions was coupled with a greater fresh weight growth rate over the first 35 days, both on upland and lowland. Two harvests of these crops were taken, but on different dates in upland and lowland conditions, making comparisons difficult. In both trials the yield of rape under upland conditions was too low to be regarded as a meaningful comparison.

A series of comparison trials including rape and radish were carried out at the Grassland Research Institute, Hurley (Sheldrick *et al*, 1981), which used various sowing and harvest dates, over several years. Curves were fitted to determine the effect of harvest date on yield, and a maximum occurred at the end of November for radish, and mid-December for rape, regardless of sowing date or year. Sowing date had a significant effect on radish, reducing yield by 0.12 t ha^{-1} for each week's delay in sowing after 19 July, but sowing date had no significant effect on rape.

No other experiments have been reported which used a range in both sowing and harvest dates, but kale has been included in several trials in which sowing date alone was varied, with varying results. It was generally found that delaying sowing later than mid-June reduced yield (Farrar, 1963; NOSCA, 1978; Dibb and Brown, 1964), but whilst an additional advantage from a May sowing was reported by some (Thompson and Willcock, 1963; Harper and Compton, 1980) others found little or none (Dibb and Brown, 1964; Lake *et al*, 1973). As with Raphanobrassica and rape, it was also found that delaying harvest past November reduced yield (Thompson and Willcock, 1963; SAC, 1981).

2.3.2 *Dry matter content (DMC)*

The effect of lengthening the growing season was to increase the DMC of all varieties (NOSCA, 1978; Harper and Compton, 1980). The exception was with Maris Kestrel kale, which had a DMC of 13.3% from a May sowing compared with 14.4% from a June sowing (Harper and Compton, 1980), but at two later sowings Maris Kestrel kale DMC reduced from 16.4 - 13.1% from a June-July sowing (NOSCA, 1978). Although Raphanobrassica and radish tended to have lower DMC, there was still a reduction with a shorter growing season, with Crail having a value as low as 8.7% from a mid-August sowing (NOSCA, 1978). In both the NIAB (1980) and SAC (1981) kale variety trials, which employed both autumn and winter harvests, the DMC increased at later harvests, and earlier kale variety trials have reported similar results (Castle *et al*, 1957; Prytherch *et al*, 1959).

2.3.3 *Digestibility (Digestible organic matter as % of dry matter, D)*

The effects of length of growing season on D are not clear-cut. D was reduced, in both Raphanobrassica and rape, from a July to an early August sowing at SPBS (McNaughton and Ross, 1978), but increased from a June to July sowing at NOSCA, along with kale and radish (NOSCA, 1978). Lair rape and Slobolt radish also increased in D from a July to August sowing, but in contrast Crail radish decreased. Sheldrick *et al* (1981) found no significant effect of sowing date on the D of rape or radish, and little effect of harvest although there was a slight increase until November with rape. The NIAB kale variety trials showed a similar increase in D at a winter compared to an autumn harvest (NIAB, 1980).

2.3.4 *Crude protein content (CPC)*

Few reported experiments have measured CPC over different lengths of growing season. At SPBS, in both rape and Raphanobrassica, the effect of delaying sowing from early July to early August was to increase the CPC, from 18.3 - 20.5% for Raphanobrassica, and 15.7 - 19.5% for Lair rape (McNaughton and Ross, 1978). In NIAB kale variety trials the CPC was slightly higher from the winter than the autumn harvest (NIAB, 1980) and a similar trend was evident with the leaf CPC of Giant rape at Trawscoed (Jones, 1959).

2.3.5 *S-Methyl Cysteine Sulphoxide (SMCO)*

SMCO has been identified as the primary toxic factor causing kale anaemia and it is present in all the fodder species considered here. The highest levels occur in kale. The level in all four types was shown to increase at later harvests (Whittle *et al*, 1976), though only two early harvests were taken of Raphanobrassica and radish. The greatest increase, from 8.27 - 14.42 g/kg DM was in Maris Kestrel from a December-January harvest. However, increasing the length of growing season through earlier sowing had the opposite effect of decreasing SMCO levels (NOSCA, 1978). Further information on this aspect is required.

2.3.6 *Flowering*

Fodder radish is an annual, and thus early sowing leads to autumn flowering, a trait that the hybrid Raphanobrassica has inherited to a certain extent. Experiments have shown that there is variation in the expansion of flowering between radish varieties, with Ringot, Rapide and Siletta being quicker to flower than Raifort Champêtre, Slobolt and Neris (Boyd and Dickson, 1966; Sheldrick and Young, 1977;

Furber, 1978). The response to sowing date suggests a daylength control of flowering, and variations between sites support this hypothesis. Sheldrick *et al.* (1981) observed no extensive flowering with Slobolt and Neris at Hurley, in Southern England, when sown as early as 10 July. In contrast, at the higher latitudes of Aberdeen, with a longer summer daylength, Slobolt flowered profusely from a 10 August sowing (NOSCA, 1978). The lack of flowering in Crail in these conditions was thus an indication of its high resistance to flowering.

The flowering of Raphanobrassica is a more variable response than that in radish, in spite of the earlier sowing dates generally employed. Thus, whilst at ESCA 23% of the plants flowered from a May sowing and 6% from a June sowing in one season (Harper and Compton, 1980), the following season 50% flowered from a June sowing, and 5% from a July sowing (ESCA, 1978).

The effect of flowering on plant composition was shown by a radish variety trial reported by Furber (1978). Siletta, Neris and Slobolt were compared over three seasons, and it was observed that the greater the degree of flowering, the lower the D-value and CPC, and the higher the crude fibre content of the plants. This has the effect of reducing the nutritional value of the crop, and also the animal intake, as the crop becomes less acceptable. Another deleterious effect of flowering is that measurements of kale plant parts has shown that secondary leaves and flowering parts were particularly high in SMCO content (Whittle *et al.*, 1976).

2.4 Plant Population

Introduction

Plant population density is another of the basic agronomic factors affecting the growth of a crop, and yet there has been even less investigation of its affects on forage crops than on any of the other factors considered. This is in spite of it being one of the most easily controllable factors, depending only on having the equipment to sow at a particular planting density. Thus there is very little information available on optimum plant populations, nor how this is affected by other factors.

2.4.1 Yield effects

The first reported plant population trial with fodder crops was carried out in 1927 (Hunter-Smith and Willaims, 1927). Marrowstem kale was used, planted at spacings giving densities of 2-7 $pl.m^{-2}$, and the results indicated that the best yields were obtained from the highest populations. Ten years later a similar experiment was carried out at Auchincruive (Cochrane and Macfarlane, 1937). Densities in the range 3-10 $pl.m^{-2}$ were used and an optimum density for fresh weight yield of 7 $pl.m^{-2}$ was found.

It was not until 1960 that a more thorough investigation into the subject was reported, although based on experiments carried out in the early 1950's, and this still remains the most detailed work. It was carried out at Leeds, using both marrowstem and thousand-head kale (Holliday, 1960) and Essex Giant rape (Holliday, 1960a). Marrowstem kale, grown over three years, showed an asymptotic yield/density relationship, both for total and partitioned dry matter yields (Figure 2.4.1). Thousand-head kale showed a similar response, although it had a much higher leaf : stem ratio, and a secondary shoot component to

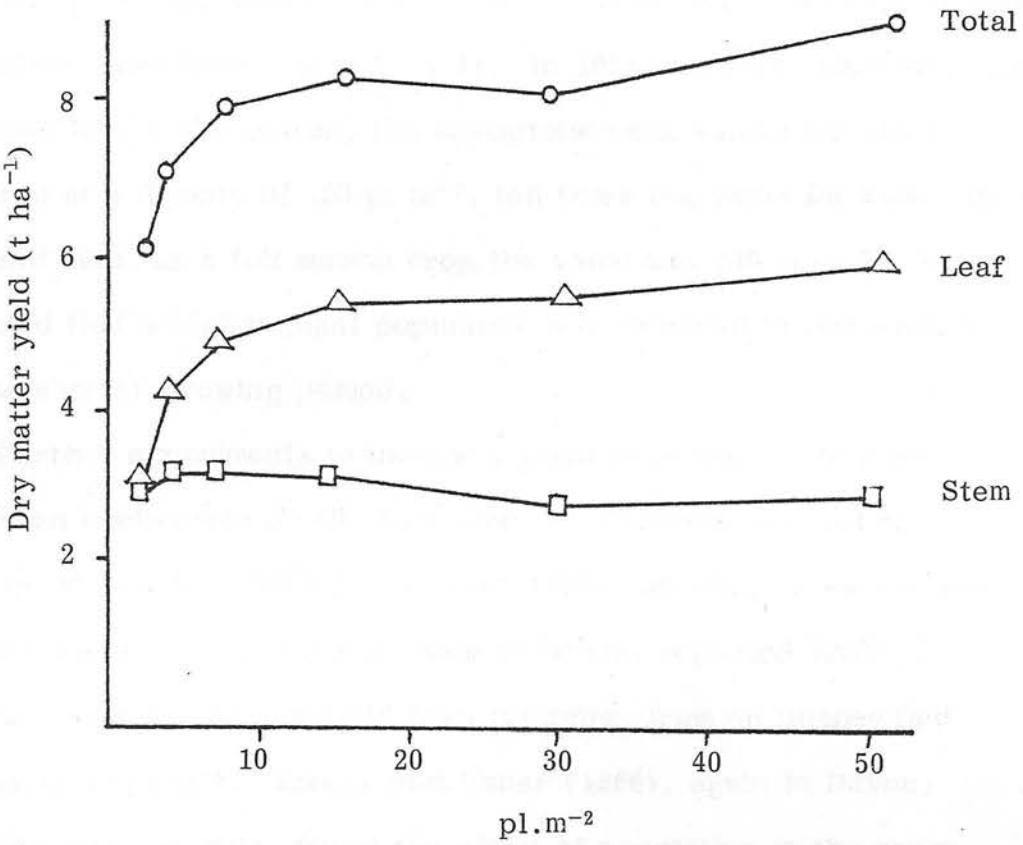


FIGURE 2.4.1: Dry matter yield (t ha^{-1}) in relation to plant population density (m^{-2}) in marrowstem kale, grown over 3 years at Leeds. From data of 1959 MSc Leeds University Thesis by Roebuck, reported by Holliday (1960).

yield at low densities. For both varieties the asymptotic peak value for yield was reached at a plant population density of about 15 $pl.m^{-2}$.

Essex Giant rape also showed an asymptotic relationship between yield and plant population density, but attained maximum yields at higher populations than kale (Figure 2.4.2). In 1951 and 1952, when the crop was sown late in the season, the asymptotic peak values for yield occurred at a density of 150 $pl.m^{-2}$, ten times the value for kale. In 1953 and 1954, as a full season crop, the value was 100 $pl.m^{-2}$. This indicated that a higher plant population was required to compensate for the shorter growing period.

Further experiments to include a plant population component have been exclusively on the kale crop, and broadly support the findings of Holliday. Dibb and Brown (1960), working on marrowstem kale and Canson thousand-head kale in Devon, reported small differences in dry matter yield from thinning, from an unspecified density, to 13 $pl.m^{-2}$. Toosey and Usher (1966), again in Devon, using marrowstem kale, found the effect of population in the range 30 - 190 $pl.m^{-2}$ to be small. Skaland and Hillestad (1971) reported on trials with marrowstem kale from 1952-1968, and quoted an optimum population of 20 $pl.m^{-2}$.

Johnston (1960), using Canson thousand-head and marrowstem kale and later also Maris Kestrel kale (Johnston, 1971), noted an interaction between plant population density and fertility. With a high level of nitrogen (120 kg ha^{-1}) there were no differences in yield due to plant population in the range 2-11 $pl.m^{-2}$, but with no additional nitrogen there was an advantage in favour of a denser crop.

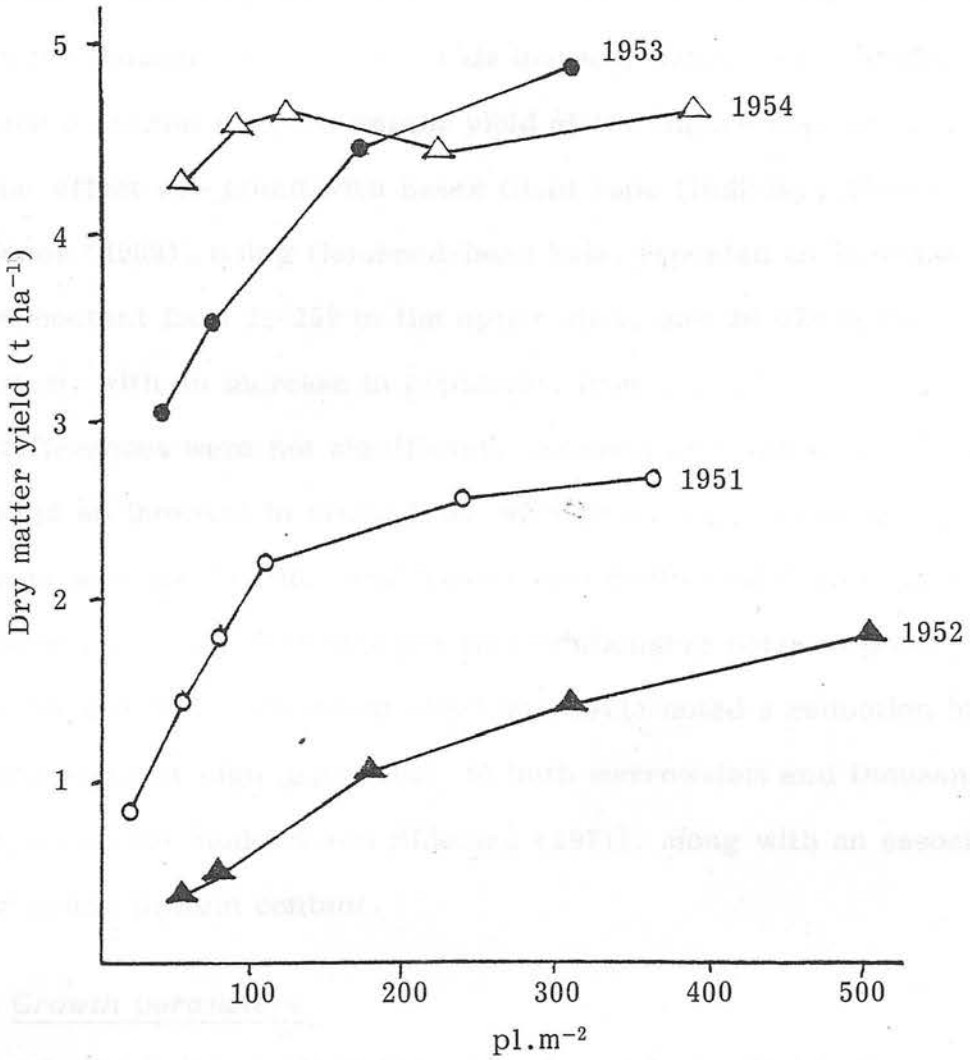


FIGURE 2.4.2: Total dry matter yield (t ha^{-1}) in relation to plant population (m^{-2}) in Essex Giant rape, grown from late July - October 1951-52 and April - October 1953-54, at Leeds (Holliday, 1960a).

2.4.2 *Plant composition*

In the experiment of Holliday (1960) dry matter content tended to increase with population, from 12.6 - 13% in leaf and 9.1 - 11.6% in stem for marrowstem kale, and 15.1 - 16.6% in leaf and 18.7 - 20.4% in stem for thousand-head kale. This increase balanced the slight drop that occurred in fresh weight yield at the higher populations. A similar effect was noted with Essex Giant rape (Holliday, 1960a).

Jones (1962), using thousand-head kale, reported an increase in fibre content from 21-25% in the upper stem, and 36-42% in the lower stem, with an increase in population from 7-21 pl.m^{-2}, though these differences were not significant. Skaland and Hillestad (1971) also found an increase in crude fibre with increased population, as well as an increase in DMC, and Toosey and Smith (1964) and Toosey and Usher (1966) affirmed this positive relationship between plant population and DMC. Johnston (1960 and 1971) noted a reduction in leaf percentage at high population, in both marrowstem and thousand-head kale, as did Skaland and Hillestad (1971), along with an associated drop in crude protein content.

2.4.3 *Growth parameters*

Leaf area index (LAI) is the ratio of crop leaf area to crop ground area, and is thus directly affected by changes in plant population density. This fact was made use of in a series of experiments on kale conducted by Watson at Rothamsted, in which crops were repeatedly thinned to maintain a certain level of LAI (Watson, 1956; Watson and French, 1962). In the second of this series two population levels were included, which illustrated the effect of population on the seasonal trends in LAI (Figure 2.4.3). The two plant populations used were 11 pl.m^{-2} and 21 pl.m^{-2}, and the results showed that although the higher

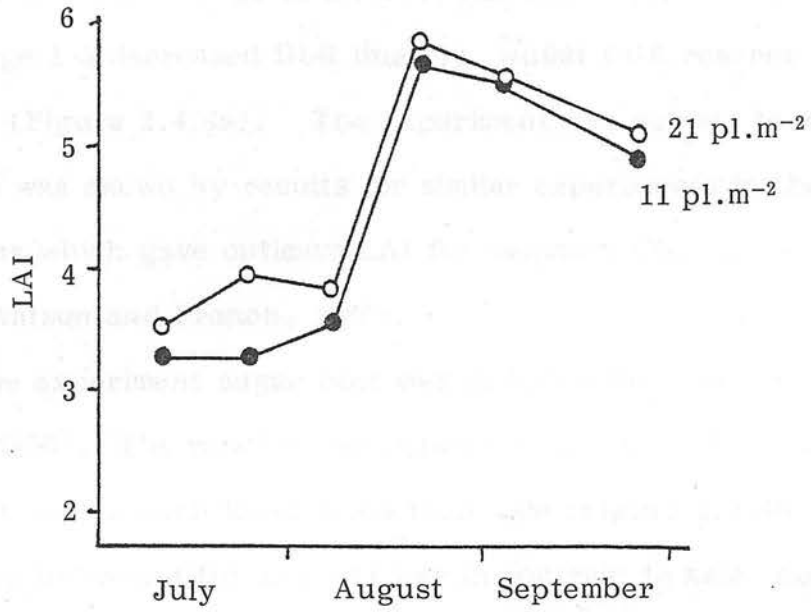


FIGURE 2.4.3: Change with time in LAI of Canson thousand-head kale at two populations, 11 and 21 pl.m^{-2}, in 1955 at Rothamsted, Herts (Watson and French, 1962).

population crop had a greater LAI by early August this difference was very small. The crops were sown at the end of March, and after four months of growth, the lower population had compensated in leaf growth for its initial disadvantage.

From the results of the thinning experiments, CGR and ULR were calculated for a range of LAI. It was found that increasing LAI in the range 1-5 decreased ULR linearly, whilst CGR reached a peak at L = 2.7 (Figure 2.4.4a). The experiment was subject to large errors, as was shown by results for similar experiments in the following two seasons, which gave optimum LAI for maximum CGR of LAI = 3.7 and 4.7 (Watson and French, 1962).

In one experiment sugar beet was included for comparison (Watson, 1956). The relationship between ULR and LAI was again linear, but with a much lower slope than kale (Figure 2.4.4b). The relationship between CGR and LAI was in contrast to kale, not significantly different from linear (Figure 2.4.4b), showing that the optimum LAI was higher than the range used in the experiment.

Although these experiments cannot be regarded as accurate, they do indicate a difference in response of kale and sugar beet to increasing LAI. Support for such differences can be found in theoretical considerations of canopy morphology. Kale tends to have horizontal leaves concentrated at the top of tall stems, whereas sugar beet has a rosette pattern of growth, with angled leaves radiating from close to ground level, with the upper leaves more steeply angled than the lower leaves. The rosette arrangement should be more efficient at higher LAI, as light can penetrate through the canopy more easily. This was confirmed by Leach and Watson (1968), using phytometers to measure the gradient of photosynthesis within several crops. Photosynthesis

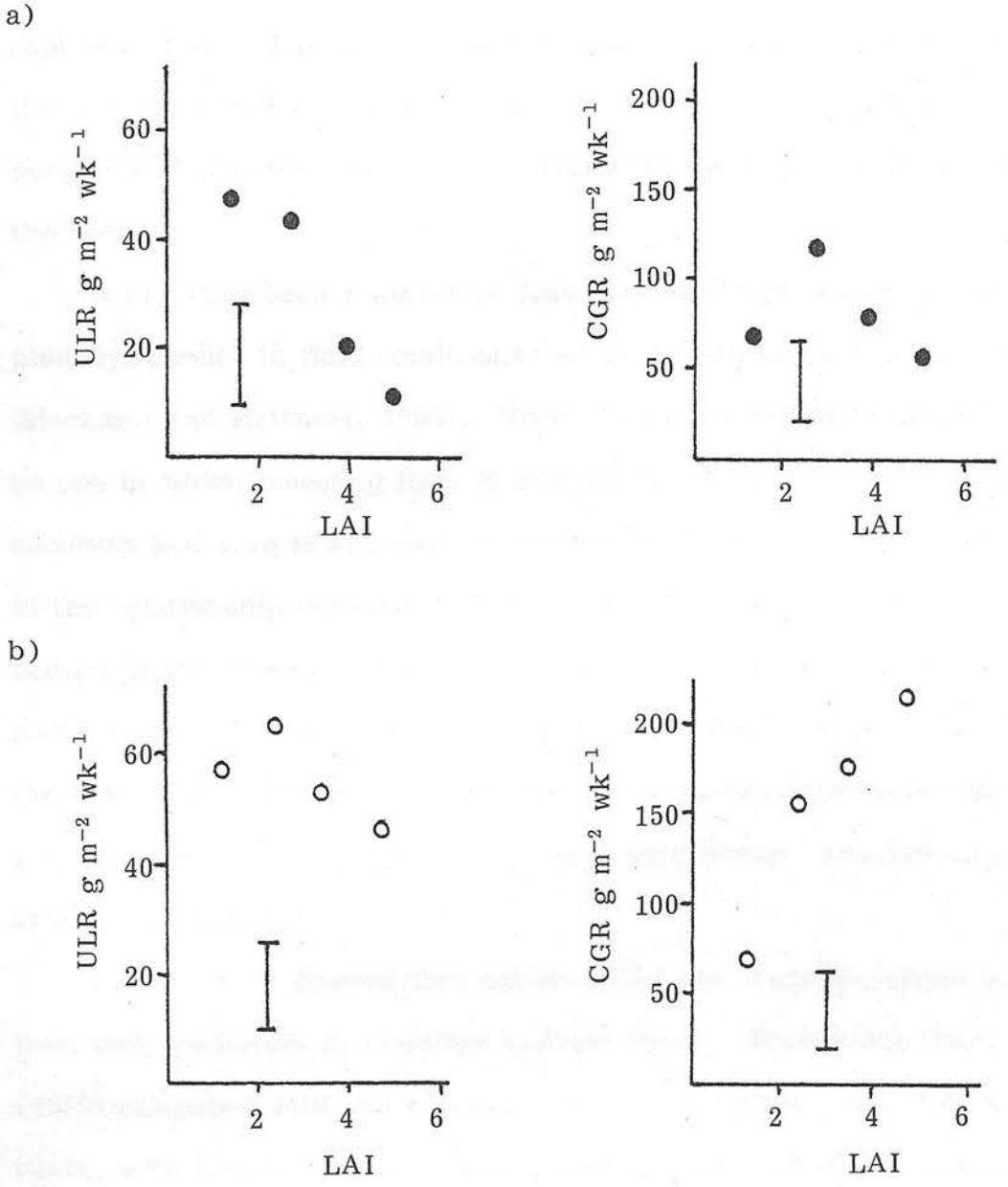


FIGURE 2.4.4: The dependence of ULR and CGR on LAI in a) kale, and b) sugar beet, in 1954 at Rothamsted, Herts. Bars represent LSD (P = 0.05) (Watson, 1956).

decreased down the kale crop profile much more quickly than down a sugar beet profile, and also a unit leaf area of kale tended to intercept more light, due to its greater thickness. Szeicz (1974) found, through stratified sampling of a thousand-head kale crop that the bulk of leaf area was always concentrated in the upper 30-40 cm of the crop.

It has long been known that leaves become light saturated for photosynthesis, in field conditions, at levels well below full sunlight (Blackman and Matthari, 1905). Thus the most productive canopy will be one in which incoming light is intercepted in such a way that the maximum leaf area is exposed to optimum light levels. This is reflected in the relationship between CGR and LAI. The more efficient the canopy is at utilising available light the higher the optimal LAI for maximum CGR. Reduction in CGR at supra-optimal LAI is caused by the lower leaves being at a light level below their compensation point, i.e. photosynthesis at a lower level than respiration, causing a net loss of assimilates.

Black (1963) showed that optimum LAI was linearly related to total daily radiation in *Trifolium subterraneum*. Watson and Witts (1959) compared wild and cultivated beets, and found that cultivated beets, with a more erect leaf habit, had greater ULR at equivalent LAI. The effect of leaf angle has also been demonstrated in cereals. Yields of maize were increased when the upper leaves were held more erect (Pendleton *et al*, 1968), and barley seedlings were found to absorb more CO_2 with more erect leaves, when the LAI was above 3 (Pearce *et al*, 1967).

The implications of such work are that kale has a low optimal LAI so high plant populations may give an early advantage, but this

could be balanced by inducing a supra-optimal LAI later in the season. This helps to explain the lack of response of kale yield to increased population levels above 20 $pl.m^{-2}$ found by most workers. However, the experiment of Watson and French (1962) showed that differing populations may reach a similar LAI later in the season (Figure 2.4.3). However, no firm conclusions can be reached on such little evidence, and on a single crop type.

2.5 Utilisation

The efficiency of utilisation of forage crops is a factor that is often disregarded when considering their yield, and yet it is one of the most critical factors determining the ultimate value of the crop. Geisler *et al* (1979) constructed a model of a production system in which lambs were fed on an autumn catch crop. It was found that the predictions of profitability produced were very sensitive to the assumption made on crop utilisation values, and that there is a lack of basic information in this area.

Most of the forage crops in the United Kingdom are utilised by grazing *in situ* (Mackay, 1971), and this is a system that inevitably involves a degree of crop wastage. The main difficulty of any investigation is to determine the amount of wastage involved. Most of the experiments on utilisation in England and Wales have been carried out by ADAS, and in a review of this work, Bastiman and Slade (1978) discussed this difficulty. In some experiments wastage was assessed visually, and in others using a technique of smapling quadrat areas for yield before and after grazing. Work at Liscombe EHF indicated that the quadrat measurements of wastage produced higher figures than visual estimation.

Another difficulty encountered was the timing of measurement. Broken and trodden leaves tended to quickly rot and disappear, and if sampling was delayed, lower wastage than in fact occurred could be inferred, particularly in wet conditions. Thus, whilst many experiments assumed leaf material to be fully utilised, estimates of leaf wastage of 39% were made in a Yorkshire/Lancashire region experiment, and similar high levels were recorded at Liscombe EHF. These findings are in agreement with those of Greenall (1958), working with grazing wethers on rape in New Zealand.

Most of the grazing trials in the United Kingdom have been with lambs, and the crop most often used has been rape (Table 2.5.1).

TABLE 2.5.1: Waste of forage crops (% DM) when grazed *in situ* by lambs, as measured in EHF or Regional ADAS trials (Bastiman and Slade, 1978).

	Rape	Kale
Liscombe EHF	20-70	25-70
South-West	Down to nil	
Wales	0-40	-
Yorks/Lancs	17	-
East Midlands	20	0

Visual assessments of wastage were converted to percentage figures, and some of the variation in values were due to the different estimation methods used. Other factors that Bastiman and Slade (1978) identified were stocking pressure, methods of grazing, weather conditions, soil type and crop type.

2.5.1 Stocking pressure

An experiment in the South-west region of England demonstrated the effect of stocking pressure. At one site over 5000 lamb grazing days per hectare were achieved with only 9% wastage, but also with lamb growth rates of only 70 g day^{-1}. At another site, on a poorer crop, only 1500 lamb days per hectare were achieved, and wastage was 33%, but lamb growth rates were double those at the first site. Thus increased percentage utilisation was at the expense of growth rate. Similar effects were shown by an experiment using lambs at WOSCA (Paterson *et al*, 1977). Three stocking pressures were used, defined in terms of dry matter allowance per unit liveweight, and the higher the stocking pressure the greater the utilisation, but the lower the growth rate and thus the longer the time to slaughter (Table 2.5.2)

TABLE 2.5.2: Performance of Blackface wether lambs on English Giant rape at WOSCA. Stocking pressures to allow, 9%, 6.75% or 4.5% of liveweight in daily dry matter allowance in 1975, and 7.5%, 6% or 4.5% in 1976. Standard for slaughter minimum weight of 28 kg in 1975, 30 kg in 1976 (Paterson *et al*, 1977).

Stocking pressure	Utilisation % 1975 leaf	1975 stem	1976 leaf	1976 stem	Av. liveweight gain (g day^{-1}) 1975	1976	Days to slaughter 1975	1976
low	44	3	59	-1	86	169	38	49
medium	49	15	70	23	100	138	45	70
high	74	25	82	68	64	119	64	81

The 1976 lambs were slower to reach slaughter weight as they had to achieve a greater body weight. The reasons for the different trend between low and medium stocking pressure in growth in 1975 were not clear, but it was not reflected in the time to slaughter.

Greenall (1958) found that with a constant stocking rate, a doubling of rape yield (effectively halving stocking pressure), quadrupled wastage, and Keane (1974) found that the best lamb performance was on rape with the lowest utilisation rate. However, in two lamb grazing trials of rape and Raphanobrassica, no significant effect of stocking pressure on lamb performance, as assessed by liveweight gain, was found (McNaughton, 1979, 1981).

In general there is agreement that greater utilisation occurs at higher stocking pressures, and also that greater utilisation leads to a lower growth rate. A possible reason for this was shown by the results of Paterson *et al* (1977). At the lowest stocking pressure the lambs showed a strong preference for leaf over stem, and increasing stocking pressure had a greater effect on the utilisation of stem than leaf, so that as the stocking pressure increased stem formed a greater proportion of the diet (Table 2.5.2). Leaf is generally considered to have a higher nutritive value than stem (Dent, 1963a,b), and thus the best diet will be that containing the greatest proportion of leaf, i.e. that from a low stocking pressure.

The preference for leaves of lambs grazing rape has also been noted by other workers (Greenall, 1958; Johnston, 1961; Keane, 1974; Furber, 1978), and also for dairy cattle grazing kale (NIRD, 1959). However, Greenall (1958) concluded that the effects of selective grazing were small, as the digestibility and nutritive value (measured as starch equivalent and total nutrient content) of samples from grazed and ungrazed rape were similar.

2.5.2 *Grazing method*

There has been little work on this factor, and the most detailed study was carried out at Liscombe EHF (Bastiman, 1977). Two grazing

techniques were compared, strip grazing, where the fence was moved every other day, and block grazing, where the fence was moved weekly, with lambs, on both rape and kale (Table 2.5.3).

TABLE 2.5.3: The effect of grazing system on utilisation of rape and kale at Liscombe EHF (Bastiman, 1977).

	Block grazed	Strip grazed
Daily liveweight gain (kg)	0.11	0.10
Lamb grazing days/ha	3504	3081
Dry matter wasted (%)	27	38

Block grazing gave more lamb grazing days without any reduction in growth. Contrary to expectations strip grazing produced lower utilisation. Similar observations have been made by Rosemaund, High Mowthorpe and Gleadthorpe EHF (Bastiman and Slade, 1978). At Rosemaund, strip grazing was more effective in dry conditions, suggesting that the lower utilisation from this method was due to greater trampling and soiling of the crop in the crowded conditions of a narrow strip. At Gleadthorpe, cattle, rather than sheep were used, and strip grazing again produced more wastage than block grazing.

The importance of providing an area of grass run-back has been emphasised by several EHF's (Bastiman and Slade, 1978). Apart from reducing the risk of dietary disorders it provides a clean lying area, though a muddy track between crop and lie-back can frustrate this advantage.

2.5.3 Weather conditions and soil type

These two factors are linked together, in that the combination of wet conditions and a mineral soil lead to the contamination of the crop

with mud, and hence its rejection, as mentioned with regard to grazing methods. Thus the highest reported wastage levels in ADAS trials, of 70%, were from Liscombe EHF under very wet conditions (Table 2.5.1) (Bastiman and Slade, 1978).

2.5.4 Crop type

Most of the experiments on utilisation have used lambs grazing on rape, and, in comparisons with other forage crops, rape is equivalent or superior for the fattening of lambs. In spite of its popularity in England, little work has been done on kale utilisation, and there are no reported comparisons with other crops. Fodder radish, on the other hand has been studied in several trials, and generally with unfavourable results.

In two seasons at WOSCA, in comparison with rape, lamb weight gains were similar in one year and poorer in another, on radish, and in both years grading results and killing-out percentages favoured rape (Boyd and Dickson, 1966). In three years of trials at High Mowthorpe EHF store lambs failed to make any progress on Ringot Rapide or Slobolt radish, and in fact many lost weight (High Mowthorpe, 1966). Sheldrick and Young (1977) also found a weight loss when feeding Silentina radish, although the sudden change of diet rather than the crop *per se* was blamed. The poor performance on radish would seem to be associated with a problem of palatability, particularly when the plants were flowering. Boyd and Dickson (1966) reported that young plants were taken readily, but once flowering started only lower leaves were selected, and once pods had formed the plants were only used as shelter. Furber (1978) observed that rape was usually accepted more readily than radish, particularly if the radish crop became overmature. In contrast, Johnston (1962) found radish to be as palatable as rape,

and better than kale, even when flowering. However, he did later observe that sheep tended to eat the stems rather than the leaves of flowering radish plants (Johnston, 1963).

There have also been several grazing trials involving Raphanobrassica and rape, most of which gave an inconclusive result, but with a tendency to favour rape. The ADAS Northumberland area reported no significant difference in the average liveweight gain of lambs on Canard rape and Raphanobrassica, 147 and 138 g day^{-1} respectively (McNaughton, 1979). A trial at WOSCA similarly found no significant difference in the performance of lambs on rape and Raphanobrassica, in either daily liveweight gains or net carcass production (g kg^{-1} DM offered) (McNaughton, 1979). Gains were satisfactory on both Lair and Raphanobrassica at the Grassland Research Institute, Hurley, though slightly higher on rape. Slight anaemia problems were noted on both crops, but the lambs recovered without a change of diet. It was observed that the rape was more quickly utilised than Raphanobrassica (McNaughton, 1979).

There have been other suggestions of problems with the palatability of Raphanobrassica. At the Rowett Research Institute, after three weeks, the lambs stopped grazing, and began to lose weight, though they later resumed feeding and regained in weight. A similar trial showed initial rejection of Raphanobrassica by cattle, but after frosting it was readily accepted (McNaughton, 1979). In contrast, plots of Raphanobrassica have been grown at several commercial farms in East Scotland, and acceptability and utilisation by lambs was reported to be as good as with rape (ESCA, 1978).

The most recent, and most detailed grazing trial involving Raphanobrassica was organised by SPBS, and carried out at three

sites, with lambs grazing Lair rape and Raphanobrassica at three stocking rates (McNaughton, 1980). Wastage was assessed by quadrat sampling, and was found to be high on both crops, but highest with Raphanobrassica. Analysis of lamb liveweight growth showed a highly significant and better performance of lambs on rape over the last three of the seven weekly sampling dates (McNaughton, 1981). Stocking rate had no significant effect alone, but showed a significant interaction with crop type on three dates at one site. Rape had the greatest advantage over Raphanobrassica at the highest stocking rate.

The reasons for the poorer performance of stock grazing alternative fodder crops to rape have not been established. Lower palatability is a factor, which could lead to a higher degree of wastage, particularly initially, with animals damaging and trampling crops, rather than grazing them. The architecture of the crop could also play a part here. It has been noted that rape and kale, with a higher canopy, were less prone to wastage through soiling of leaves than root crops (Bastiman, 1977), and work on Dutch turnips has shown that varieties with more brittle leaves had higher levels of wastage (Bastiman and Slade, 1978). Fodder radish and Raphanobrassica both have a lower leaf canopy than rape, with less stem, and more rigid and brittle leaves, and could thus be more prone to wastage.

Another possible factor is the composition of the crop. Fodder radish, and Raphanobrassica in particular, tend to have a lower dry matter content than rape, except when they are flowering, when dry matter content increases, in association with an increasingly fibrous and indigestible stem growth (Section 2.3.6). Also, high levels of SMCO have been measured in the flowering parts of kale (Whittle *et al*, 1976).

The importance of utilisation is shown by the influence it has had on the popularity of crop types. The problems with acceptability and the need for acclimatisation to fodder radish have been the main factors in its continued restricted use (Furber, 1978), and the poor performance of Raphanobrassica in grazing trials has been one of the main constraints to its commercial development (McNaughton, 1981).

CHAPTER III

Methods

3.1 Crop Varieties

Throughout the project the same three crop varieties were used. This was to ensure a continuity, enabling comparisons to be made between experiments made in different seasons. The genetic variability within a variety was assumed to be at a low level, and although different seed batches were used in each year, all differences between trials were attributed to environmental effects, rather than genetic differences within each variety.

The varieties were chosen from three different species, *Brassica oleracea* (kale), *Brassica napus* (fodder rape), and Raphanobrassica. Raphanobrassica is an inter-generic hybrid of kale and *Raphanus sativus* (fodder radish) (Section 2.1). Kale is the most important of the leafy forage brassicas grown in the United Kingdom. Fodder rape, although not so widely grown in the UK as a whole, is the more popular crop in Scotland, where its quick growth is exploited as an autumn feed for fattening lambs. Kale is slower growing and more hardy, and is usually utilised later in the season, generally by dairy cattle (Mackay, 1971).

The varieties of kale and rape used were Maris Kestrel and Lair, respectively. These were the leading commercial varieties at the time of the start of the project. By the end of the project both varieties were outclassed by others (NIAB, 1980) but were still in widespread use.

The situation with Raphanobrassica was different. It is an inter-generic hybrid developed by the Scottish Plant Breeding Station (McNaughton, 1977), with the intention of combining the rapid growth and clubroot and mildew resistance of fodder radish with the digestibility and hardiness of kale. There was one seed stock available, which was used in all the trials. The hybrid was not commercially available, and

had only undergone a few yield performance trials at the onset of the project (Section 2.2). These preliminary trials indicated that further studies on the forage potential of this crop were justified.

3.2 Sowing

In all experiments the seed was sown using a "Stanhay" precision drill, with five units which, in most cases, were spaced 25 cm apart. In the 1978 experiment the spacing was 51 cm. The same belts were used for Lair and Maris Kestrel, but a belt with a larger hole size was used with Raphanobrassica, to accommodate its larger seed size. Before sowing the seedbeds were prepared by rotovating and rolling, as necessary, to obtain a fine, firm and weed-free surface. Fertiliser was applied to the seedbed by hand and incorporated during seedbed preparation.

3.3 Harvesting Method

The three middle rows of each five-row plot were used for harvests, leaving an outside row on each side as a guard row, and the 30 cm at the ends of each row were also discarded. The plants were cut at ground level, using scissors, secateurs or shears, as appropriate to plant size, counted, and their fresh weight recorded using a tripod and spring-balance, accurate to 0.1 kg. Where samples weighed less than 1 kg, they were bagged and taken back to the laboratory, to be weighed on a 3 kg balance, accurate to 0.1 g.

3.4 Sampling Method

Five, ten or twenty plant sub-samples were taken from the harvested plants of each plot. The number was chosen according to the

size of the plants at that particular harvest, to give the greatest sample size possible without too many being in excess of 1 kg. This was found to be the greatest sample weight that could be easily handled in the laboratory.

Each sample was separated into a leaf, petiole and stem fraction. The leaf fraction was defined as the leaf lamina plus mid-rib, down to the point where the lamina ceased to be continuous on the petiole. Any further pieces of lamina attached to the petiole were stripped off and added to the leaf fraction. The petiole fraction was the remaining petiole, to its junction with the stem, and the stem fraction the remaining portion, including terminal buds and flowers, when present.

The fresh weight of each sample fraction was measured, and leaf number counted, including all leaves which were judged to be more than half expanded. A further sub-sample of leaf material was taken for leaf area determination, as detailed in the following section.

The material was then oven-dried, at 80°C, for at least 24 h, and reweighed. Any fresh material that could not be processed on the day of harvest was stored in a freezer at -4°C. In most cases the processing was completed within 24 h of harvest and never more than 48 h.

3.5 Leaf Area

For the 1978 experiment, and also most of the 1979 experiment, leaf area was determined by measuring the fresh weight of 20 leaf discs cut at random from the leaf sub-sample, using a 24 mm cork-borer. The weight : area ratio of the discs was determined, and hence total leaf area calculated, i.e.

$$\text{Sample leaf area} = \text{Sample leaf fresh wt} \times \frac{\text{leaf sub-sample area}}{\text{leaf sub-sample fresh wt}}$$

However, it became apparent that the method was not accurate enough to give good treatment comparisons, and after some experimentation (Appendix I), the use of a leaf area meter was adopted (LI-Cor Model LI-3000 Portable Area Meter[1]).

A sufficient number of randomly chosen leaves to give a total area of at least 500 cm^2 were passed through the meter, trimming away the back of petioles where necessary with larger leaves. The fresh weight of this sample was then measured, and the weight : area ratio determined and used as above. This method was used for the final two harvests of the 1979 experiment and all of the 1979 population experiment and the 1980 experiment.

3.6 Field Experiment Treatments

3.6.1 1978 sowing date x variety experiment

The aim of this experiment was to investigate the effects of two different sowing dates on the growth and development of the three varieties. A four-replicate, split-plot design was used, with the two sowing dates as main plots and the three varieties as sub-plots. This design was adopted for ease of cultivation, as it enabled the plots for differing sowing dates to be in separate strips, and thus mechanical cultivation and sowing of one sowing date could be carried out without damage to the plots of the other sowing date (Cochran and Cox, 1957).

The dates of the two sowings, 14 June and 19 July, were chosen to coincide with the period when these crops are normally sown in South-east Scotland. Five harvests were taken on 5 September, 3 October, 31 October, 28 November and 18 December, covering the whole period of normal utilisation in commercial practice.

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[1]Lambda Instruments Corporation, Lincoln, Nebraska.

Each of the five-row plots was 12.2 m long, and were split into five harvest plots, each 2.44 m long. At harvest the middle three rows and 1.83 m were cut, from a randomly selected harvest plot, giving a harvest area of 2.79 m^2.

With all three varieties, seeds were sown at 2.5 cm spacing, but actual plant spacing was greater and varied between treatments. This was due to differing emergence percentage between varieties, Raphanobrassica having a particularly low emergence percentage, and between sowing dates. Conditions were drier in June, which lowered the emergence percentage of the first sowing. Plant population densities at each harvest are shown in Table 6.2.1.

Fertiliser was applied before sowing at the rate of 70 kg ha^{-1} N, and 35 kg ha^{-1} P_2O_5 (ESCA, 1977). All varieties had emerged from both sowings within a week of sowing. The weather data over the growing period are shown in Appendix III. No severe frosts occurred until late November, just prior to the fourth harvest.

Raphanobrassica displayed a tendency to flower from an early sowing, a trait inherited from its radish parent, and this was evident from the June sowing in this trial. Counts of flowering plants were made at each harvest (Table 4.1.1). Flowering was defined as the stage when open flowers could be observed.

After all harvesting was completed a count of clubroot incidence (causal agent *Plasmodiophora brassicae*) was made. Five roots from each harvest plot were examined and scored on a scale of 0-3. A scale of 0 represented no symptoms and 3 severe infection. The means scores for each treatment plot, consisting of five harvest plots, were calculated (Table 3.6.1). Only one infected Raphanobrassica root was found, and there was no infection in Maris Kestrel. The infection of Lair was slight, apart from one localised area of heavy infection.

TABLE 3.6.1: Clubroot counts from the 1978 experiment. Five roots per plot were examined after the final harvest, and scored on a scale of 0 - 3. 0 = no symptoms, 3 = heavily infected. Results are the mean scores.

Replicate	June sowing			July sowing		
	RB	L	MK	RB	L	MK
I	0	0.32	0	0	0	0
II	0	0.20	0	0	0	0
III	0	1.16	0	0	0	0
IV	0.04	1.04	0	0	0	0
mean	0.01	0.72	0	0	0	0

3.6.2 1979 sowing date x variety experiment

The aim of this experiment was to examine the effect of three sowing dates on the growth and development of the three varieties, over eight harvests. Frequent harvests were taken throughout the growth period, particularly during the time of early, rapid growth, to compare differences between treatments in growth patterns, and the interaction of sowing date and harvest date.

The experimental design was again split-plot, with four replicates. Sowing dates were the main plot treatments and varieties the sub-plot. The eight harvests were taken at random from within the sub-plots. The intention was for the three sowing dates to be in mid-June, early July and mid-July, but the first sowing, on 12 June, emerged very unevenly, due to unusually dry conditions, and had to be abandoned. In consequence the three sowing dates became 3 July, 18 July and 2 August.

The crops were sown in 25 cm wide rows, with Lair and Maris Kestrel at 2.5 cm spacing. Raphonobrassica was sown at 1.7 cm spacing,

to compensate for its lower emergence percentage. However, Raphanobrassica still attained lower plant population densities than the other two varieties, particularly from the second sowing (Table 6.2.2).

In addition, the dry conditions of early summer caused a delay in the emergence of the first sowing, although they did not reduce the numbers emerging to any great extent. Weather data over the whole of the season are shown in Appendix III. Frosts occurred from late October onwards and there was snowfall in the week before the final harvest.

The first four harvests of each sowing were taken at weekly intervals, and the rest taken together for each sowing date, after a suitable period for synchronisation, at two, and then three weekly intervals, thus obtaining the growth pattern well into autumn. A scheme of sowing, emergence and harvest dates is presented in Table 3.6.2, overleaf.

Fertiliser was applied before sowing at the rate of 140 kg ha^{-1} N and 70 kg ha^{-1} P_2O_5 and K_2O (ESCA, 1977). Harvest plots were of five rows, 3.05 m long, of which the middle three rows and 2.44 m was taken, giving a harvest area of 1.86 m^2.

Sowing dates were late enough in this year to prevent flowering in Raphanobrassica. There were no problems with pests or diseases, and no evidence of clubroot infection was found.

TABLE 3.6.2: Sowing, emergence and harvest dates for the 1979 sowing date x variety experiment.

Sowing	Sowing date	Emergence date
1	3 July	23 July
2	18 July	30 July
3	2 August	13 August

Harvest date	Sowing: 1	2	3
13 August	1	-	-
20 August	2	1	-
27 August	3	2	1
3 September	4	3	2
19 September	-	4	3
17 September	-	-	4
24 September	5	5	5
8 October	6	6	6
29 October	7	7	7
19 November	8	8	8

3.6.3 1979 population x variety experiment

In 1979, in addition to the main field experiment, another, smaller plant population experiment was carried out. The aim was to investigate the effects of plant population density on the growth of the three varieties. Variation in establishment had led to differences in the plant population densities of the different varieties in the previous year's trial (Table 6.2.1), and so it was important to establish the significance of this factor.

The trial was in a four replicate, completely randomised block design, with twelve treatments consisting of the three varieties at four

densities. The trial was sown on 3 July, but due to dry conditions did not emerge until three weeks later. The seed was sown in 25 cm rows, with 1.7 cm spacing, and then singled by hand to the treatment densities, a week after emergence.

Due to low emergence percentages, of Raphanobrassica in particular, the highest density that could be achieved was 52 pl.m^{-2}, at 7.6 cm spacing. Thus the four spacings used were 7.6, 15.2, 22.9 and 30.5 cm, giving population densities of 52, 26, 17 and 13 pl.m^{-2} respectively.

Fertiliser was applied before sowing at the rate of 140 kg ha^{-1} N, and 70 kg ha^{-1} P_2O_5 and K_2O (ESCA, 1977). Each treatment plot consisted of five rows, 4.57 m long, of which the middle three rows and 3.96 m was harvested, giving a harvest area of 3.02 m^2. The harvest was taken on 5 November. No problems with pests, diseases or flowering were encountered.

3.6.4 1980 sowing date x population x variety experiment

The aim of this trial was again to examine the effect of two sowing dates on the growth and development of the three varieties, but with the additional factor of plant population density introduced as a treatment. Differences in emergence percentage led to variations in plant population density in the previous two years' experiments (Table 6.2.1 and 6.2.2). Thus it was the objective here to determine the effects of varying plant population density on growth and yield and the interactions this factor had with sowing date and variety effects.

The split-plot design was not retained, because of the complications in the statistical analysis it entailed, which would be further compounded by the addition of another treatment factor. The treatments were

completely randomised in each of three blocks, with greater plot spacings to allow mechanical cultivation and sowing of adjacent plots with different sowing dates.

The number of replicates was reduced from four to three because of the number of treatments involved, which had to be restricted to that which the labour available could harvest in one day. There were factorial combinations of three varieties, two sowing dates and four plot population densities, with three replicates, which gave a total of 72 plots.

The two sowing dates were 26 June and 24 July. Conditions on both occasions were good, and emergence was approximately one week from sowing, on both dates. The first severe frost occurred just prior to the 20 October harvest (Appendix III).

The crops were sown in 25 cm wide rows at the highest sowing density capacity of the drill, 1.7 cm spacing, for all three varieties. The required treatment densities were achieved by hand singling of the plants, one week from emergence. In spite of the high seed rate the closest spacing that could be achieved across all varieties was 5.08 cm, due to uneven emergence (Appendix II). The four plant population density treatments imposed were 5.08, 10.16, 15.24 and 30.48 cm spacing, which gave densities of 78, 39, 26 and 13 $pl.m^{-2}$, respectively.

As in the 1979 experiment there were eight harvests, taken at random from within the treatment plots. The size of treatment and harvest plots was also the same, as was the rate of fertiliser applied before sowing.

Harvesting was started four weeks after emergence, and was initially at weekly intervals, for four weeks with the first sowing and five weeks with the second sowing, and then at progressively longer

intervals, the final harvest being in mid-November. A scheme of sowing, emergence and harvest dates is presented in Table 3.6.4.

TABLE 3.6.4: Sowing, emergence and harvest dates for the 1980 sowing date x population x variety experiment.

Sowing	Sowing date	Emergence date
1	26 June	2 July
2	24 July	29 July

Harvest date	Sowing: 1	2
28 July	1	-
4 August	2	-
11 August	3	-
18 August	4	-
25 August	-	1
1 September	5	2
8 September	-	3
15 September	-	4
22 September	6	5
6 October	-	6
20 October	7	7
17 November	8	8

No particular pest problems were noted. There was some cabbage root fly and caterpillar damage to a few kale plants, and no clubroot damage was found. Weed growth, particularly in the low density treatments, became a problem, and was controlled by hand-weeding.

The June sowing of Raphanobrassica showed some flowering, at the final harvest only (Table 4.1.2). The flowering was at a low level, less than 10%, in most plants, but was, nonetheless, a significant factor,

as many plants, although not actually flowering, were elongating towards flowering, with consequent effects on growth patterns.

The worst problem encountered was some sheep damage, which occurred when some animals escaped from a neighbouring field. Fortunately only two harvests remained to be taken at the time, and even more fortunately the sheep confined their attentions mostly to the July sown rape. Almost a complete set of plots could be selected for the seventh harvest, but the final harvest of the July sown rape was severely depleted, and the results for this treatment had to be discarded.

The degree of selectivity shown by the sheep, with free access to all treatments, is of interest in itself. The unpalatability of Raphanobrassica in comparison to rape has been noted (Section 2.5), but not that of kale, nor the preference for younger rape plants. The palatability of the crops was important enough for the animals to actively seek out the preferred treatment, indicating that this could be a significant factor in intake rates, and thus utilisation efficiency.

3.7 Growth Analysis

From the collected sample data it was possible to obtain immediately total and partitioned yields, dry matter content and leaf area index at each harvest, and from these to calculate the ratios of Specific Leaf Area, Leaf Area Ratio and Leaf Weight Ratio. With the more extensive data from the 1980 variety x sowing date x population density experiment it was decided to calculate in addition the Crop Growth Rate (CGR), Relative Growth Rate (RGR) and Unit Leaf Rate (ULR). Classical analysis methods enable the mean CGR and RGR to be accurately estimated between harvests, but mean ULR cannot be calculated without

making assumptions on the relationship between total yield and leaf area (Radford, 1967).

If, however, the relationship between yield and time can be deduced, instantaneous values of CGR at each harvest can be obtained, and hence RGR and ULR calculated. The difficulty of this "functional" approach is to obtain an equation relating yield and time that is a good approximation across the whole range (Evans, 1972).

As the data in the experiment did not show any great fluctuations, the method adopted was to fit curves to each replicate set of eight harvest date yield results, using the "Curvefit" procedure of the Edinburgh Regional Computing Centre. This fitted a smooth curve through every data point, by calculating a cubic polynomial for each interval which agreed in value, and first and second derivative at each harvest date. The supplied first derivative values were thus the instantaneous values of CGR at each harvest, from which, by division by the yield and leaf area data the values of RGR and ULR, respectively, were calculated.

The sets of values thus calculated were analysed in the same manner as the other parameters. The method necessarily tended to compound the errors of two harvests, but due to the inherent smoothness of the data certain significant differences were nonetheless found to be obtainable.

CHAPTER IV

Results

Effects of Length of Growing Season

4.1 Introduction

The effects of length of growing season on the growth and development of the three varieties are considered, from the results of the 1978, 1979 and 1980 field experiments. The 1978 and 1979 trials had similar designs, in that sowing date and variety were the treatments factorally applied, and the results presented are thus the means of four replicates. In the 1980 experiment another treatment, plant population density, was introduced. In order to more clearly identify treatment effects, and also for ease of comparison with the previous two seasons, in this chapter the effects of density are removed, by considering the means of the four densities, for each sowing date and variety. The results for the 1980 experiment thus represent the means of twelve plots (the four densities, with three replicates).

In the 1978 experiment there were five harvests, at each of which both sowing dates were harvested. Only total fresh and dry weights were recorded at the first harvest, so most of the parameters are the results from the last four harvests. In both 1979 and 1980 there were eight harvests of each sowing, although not always taken at the same date (Tables 3.6.2 and 3.6.4).

A standard analysis of variance, using the Genstat programme of Rothamsted Experimental Station, was carried out on all parameters, at each harvest, with each sowing date considered separately. As the different sowing dates produced a considerable divergence in the values of many of the parameters, it was considered more appropriate to analyse them individually. Another consideration was that in the 1979 and 1980 trials the number of sowings harvested varied on certain dates, so separate analysis was easier. Where significant differences are indicated, they are at the probability level of $P < 0.05$ unless otherwise

stated. Bars on the graphs represent standard errors of difference between means.

For each parameter graphs are presented of the results for each variety and sowing, plotted against harvest date, thus showing the overall development throughout the season.

The 1978 and 1979 trials were sown to a stand, and differences in establishment percentages led to variations in plant population densities, both between sowing dates and varieties (Tables 6.2.1 and 6.2.2). The populations also tended to decrease as the season advanced. These variations are inevitable when sowing crops to a stand, but little is known of their effect on growth (Section 2.4). The second sowing of Raphanobrassica in 1979 had a particularly low population, which had noticeable effects on its growth. These effects will be more fully described and discussed in Chapters VI and VII, along with the results of the plant population trial in 1979 and the population density treatments of the 1980 trial.

As the 1980 trial included population density as a treatment, involving the thinning of the crops to specific population densities at the start of the trial, the differences in initial population density were largely eliminated. Populations still tended to decline as the season advanced (Table 6.2.4) but mean differences in population densities between treatments were never as great as in the previous two seasons.

Another factor that influenced these results was the tendency of Raphanobrassica to flower from an early sowing, a trait inherited from its radish parent. This tendency was expressed from the June sowings in 1978 and 1980 (Tables 4.1.1 and 4.1.2). Flowering was more prevalent in 1978, with over half of the plants flowering by the end of November. Flowering in 1980 began later, and was at a lower level than in 1978. Flowering induces elongation of the stems and the

production of many small, secondary leaves, and thus considerably changes the growing pattern of the crop. A more detailed description and discussion of flowering in Raphanobrassica appears in Chapters IX and X.

TABLE 4.1.1: Flowering of June-sown Raphanobrassica (%) in the 1978 field trial. (Flowering taken to be when the first open flowers could be observed.)

Replicate	Harvest date: 5/9	3/10	31/10	28/11	19/12
I	-	10	28	40	40
II	-	3	38	69	42
III	2	10	30	75	43
IV	-	7	23	51	53
Mean	0.5	7	30	59	45

TABLE 4.1.2: Flowering of June-sown Raphanobrassica (%) at the final harvest of the 1980 field trial. (Flowering taken to be when the first open flowers could be observed.)

Replicate	Population density (m^{-2}) 13	26	39	78	Mean
I	4.4	-	6.9	9.8	5.3
II	3.7	9.8	14.0	6.5	8.5
III	-	9.3	14.0	6.1	7.3
Mean	2.7	6.4	11.6	7.5	7.0

Population density mean SED = 3.11.

4.2 Total Dry Matter Yield

Total dry matter yield is the parameter most often used for comparisons of the growth patterns of forage crops. In all three seasons the growth curves were sigmoidal. There was an initial period of exponential growth, followed by a period of linear increase, and then a decline in growth rate towards an asymptotic peak value.

The 1978 field trial covered the later part of the growth period, when growth rates were declining (Figure 4.2.1). Although the final harvest was in mid-December, which is normally considered late for autumn forage crops in South-east Scotland, none of the varieties showed marked decline in yield. The growth of Maris Kestrel continued through to the final harvest, resulting in a significantly higher final yield from a June sowing. Otherwise there were no significant differences between varieties over the final three harvests.

At the two earlier harvests Lair had a significantly higher yield than Maris Kestrel, from both sowings. Raphanobrassica followed a different pattern from the two sowings. From a July sowing the growth curve was similar to that of Maris Kestrel, and in fact at no time were their yields significantly different. However, from a June sowing Raphanobrassica had a curve similar to that of Lair, and was only significantly lower yielding at the first harvest. A possible reason for this difference between sowing dates was the flowering of Raphanobrassica from the June sowing.

The one month delay in sowing reduced final yields by 2.5 - 3.0 t ha^{-1} (about 30-35%), but not the date of attainment of maximum yield, which was late October, except with Maris Kestrel, which continued to increase in yield until the end of the season. The two sowing dates had similar slopes during the period of linear increase in yield, from harvests

1-2. Thus the lower yield of the July sowing was due not to a slower early growth rate, but to the shorter period available for growth before declining temperature in autumn restricted further growth.

The 1979 field trial covered the whole period of growth, from a few weeks after emergence until mid-November, and clearly showed the similar form of the growth curves, both between varieties and sowing dates (Figures 4.2.2 and 4.2.3). As in the 1978 trial, the first two sowings reached an asymptotic yield at similar dates, but this was earlier than in the previous year, in early rather than late October, in spite of the sowing dates being later. However, the third sowing did not reach a peak until late October, indicating that such young plants may have the ability to grow on later into the autumn than older ones.

The continued growth of Maris Kestrel late in the season was again evident from the first two sowings, but not the third. In contrast Raphanobrassica showed a persistence of growth from the last two sowings but not the first, a persistence that was not shown in the 1978 trial.

The earlier harvests in this trial clearly showed that the early superiority of Lair, noted in the 1978 trial, was established from the beginning of the season. Lair had a faster initial growth rate, giving it a significantly higher yield over the first four harvests of both the first and second sowing dates. There were no significant differences between varieties from the third sowing, at seven out of the eight harvests. This was due to the high variability within the crop, associated with the later, and lower yielding, sowing. The one harvest where significant differences did occur was in early October, when Maris Kestrel had a significantly lower yield than the other two varieties.

The short growing season from the third sowing allowed Lair to maintain its yield advantage until the final harvest, when Raphanobrassica produced a slightly better yield. However, from the earlier sowings, after the first four harvests the growth rate of Lair declined, and its yield was similar to, or less than that of the other varieties. From the first sowing Raphanobrassica had a significantly higher yield at the sixth harvest, and there were no significant differences at the final two harvests.

From the second sowing Maris Kestrel had a significantly higher yield than Lair at the final harvest. However, the yield of Raphanobrassica was at all times lower than that of the other two varieties, significantly so at all but two harvests. This was probably due to its lower population density from this sowing.

The growth of Raphanobrassica was not affected in 1979 by flowering, and from both the first and third sowings the early growth curves were similar to those of Maris Kestrel (although later in reaching a higher peak yield).

A striking feature was the similarity of the growth curves of the first two sowings, in particular with Lair, though less so with Raphanobrassica, the latter due probably to the population differences. In practice, due to dry seedbed conditions after the first sowing, the plants from that sowing emerged only one week earlier than those from the second sowing (Table 3.6.2). Therefore differences in sowing date effects were not great here. In fact the final yields of the second sowing of Lair and Maris Kestrel were higher than those of the first sowing, indicating that a delay in sowing, rather than sowing in dry conditions, was marginally advantageous in overall yield terms.

Final yields were depressed by 30-35% from the third sowing, in August, but were still substantial at 3 - 4 t ha^{-1}. The magnitude of yield depression from late sowing was similar to that obtained in the 1978 trial. The second sowing of the 1978 trial had a similar yield, approximately 6 t ha^{-1}, to the first and second sowings of the 1979 trial. The emergence dates were within a week of each other, so the yielding pattern was not appreciably different between seasons.

The 1980 field trial covered a similar period to that of the 1979 trial, and again showed the pattern of sigmoid curves, with the varieties being closely grouped at each sowing date (Figure 4.2.4). There was a less marked reduction in growth rate towards the end of this season, particularly from the July sowing. All three varieties reached an asymptotic yield by the final harvest of the June sowing. This included Maris Kestrel, which was in contrast to its continued growth in the previous two seasons. From a July sowing the reduction in growth rate was less marked even at the final harvest, although there was some evidence of a small reduction in the growth rate of Lair at the seventh harvest.

There were no significant differences between varieties at the last three harvests of the June sowing. The yield of Maris Kestrel was significantly lower throughout the season, from a July sowing, due to its initial slower growth rate. From a June sowing, Maris Kestrel again had the lowest yields early in the season, but later compensated through sustaining its growth rate for a longer period.

From both sowings, as in the previous seasons, Lair had the highest early yields, but by the end of the season this yield advantage had disappeared. Raphanobrassica had a growth pattern intermediate between that of Lair and Maris Kestrel, from both sowings. This

similarity between sowing dates was in spite of the flowering of Raphanobrassica from the June sowing, though this was later, and at a lower level than in 1978.

A similarity in the early growth patterns of all three varieties at the two sowings was evident. The closer control of density in the trial helped to clearly demonstrate that sowing date does not alter final yields through changing early growth rates, but rather the duration of growth at these levels.

There was again a 35-40% reduction in final yields between sowings, and the yields, of 8 t ha^{-1} and 5 t ha^{-1}, were of the same order as those from similar sowing dates in the previous two seasons. In fact, when the final yields of the 1979 and 1980 trials, and the November harvest yields of the 1978 trial (to give a consistent comparison) were plotted against the length of growth season, in days from emergence to harvest, a clear linear relationship was revealed (Figure 4.2.5). There were no significant differences between the regressions of the three varieties, and the overall regression of the varieties gave a correlation coefficient, $r = 0.88$. Thus differences in conditions between seasons had very little effect on total final yields, and it was sowing date which controlled the yield potential of the crops. There was variation between seasons in the time to reach an asymptotic yield value, but this did not affect the relative magnitude of this value.

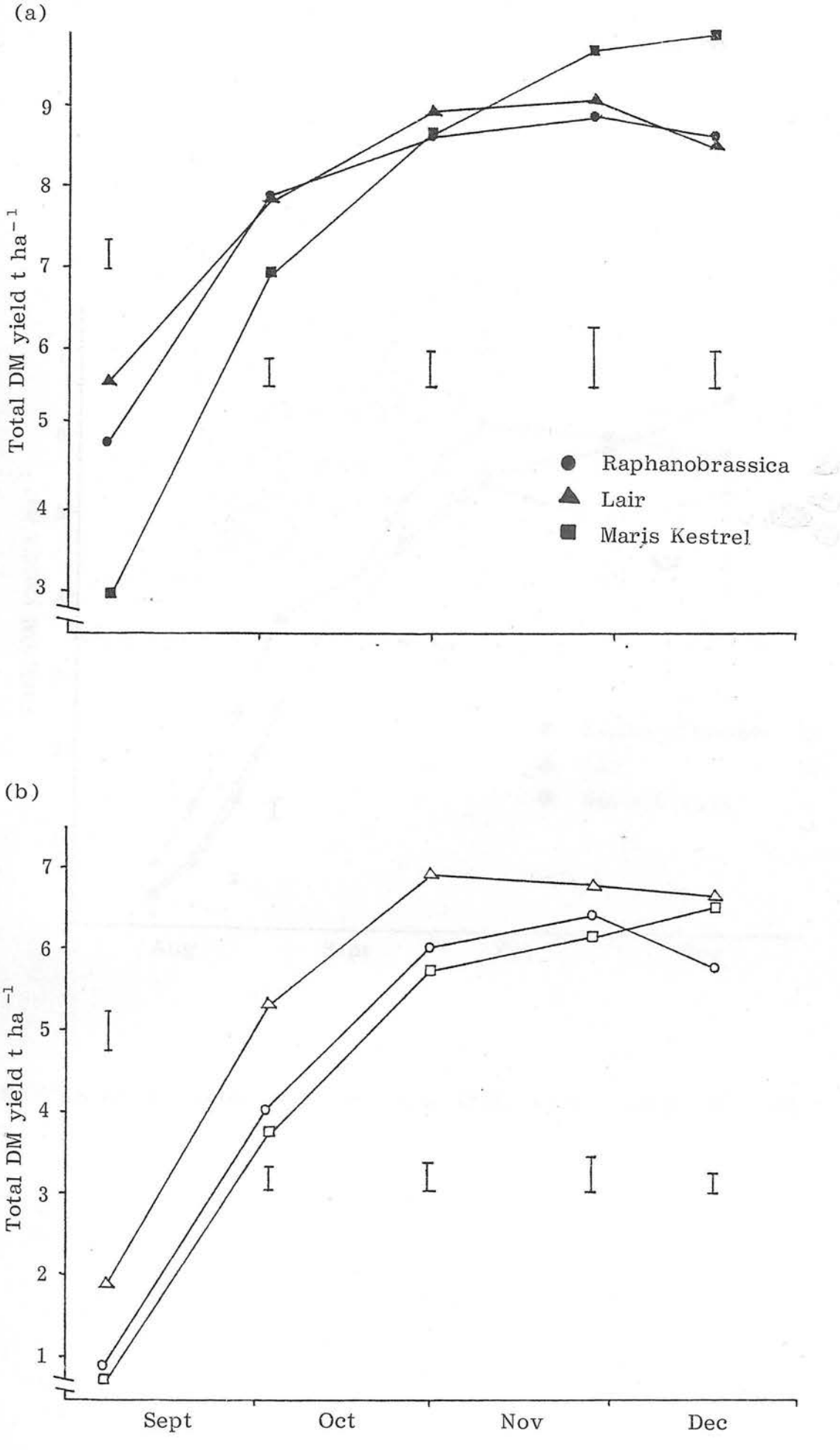


FIGURE 4.2.1: Total dry matter yield 1978. (a) June sowing;
(b) July sowing.

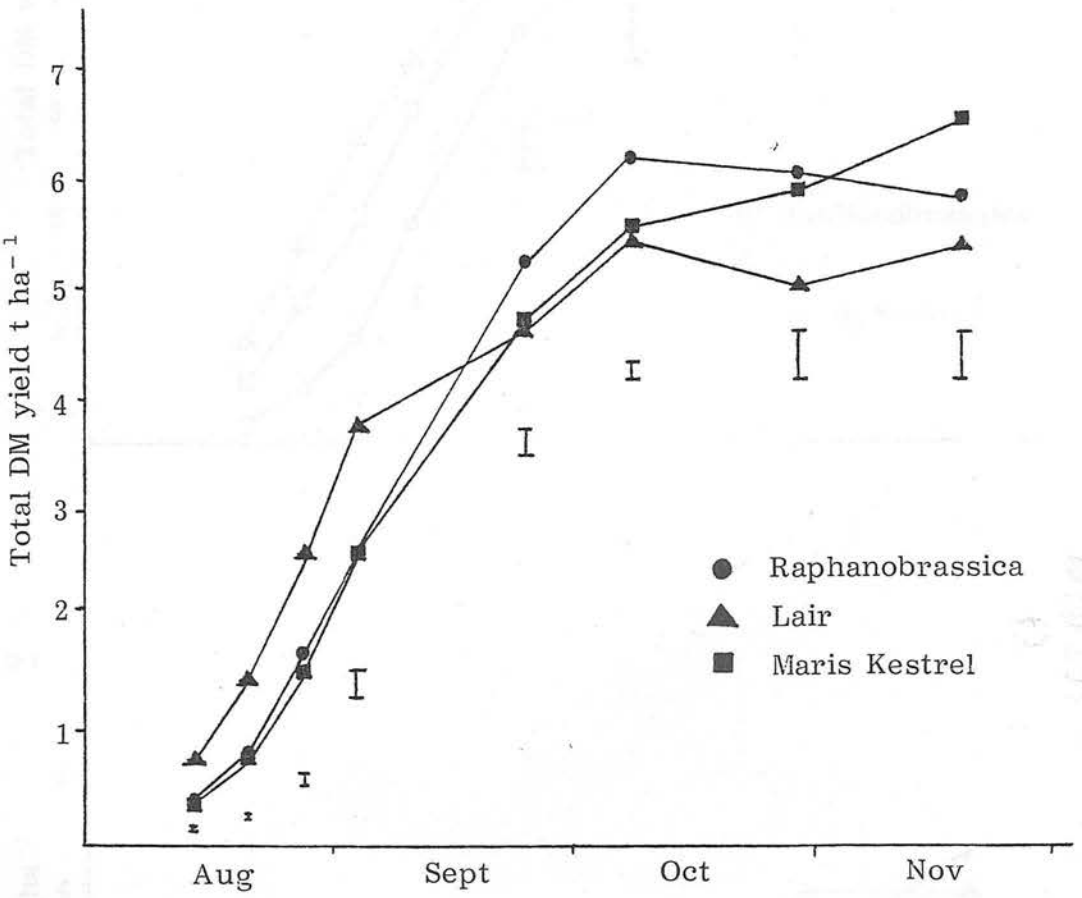


FIGURE 4.2.2: Total dry matter yield 1979. First sowing (early July).

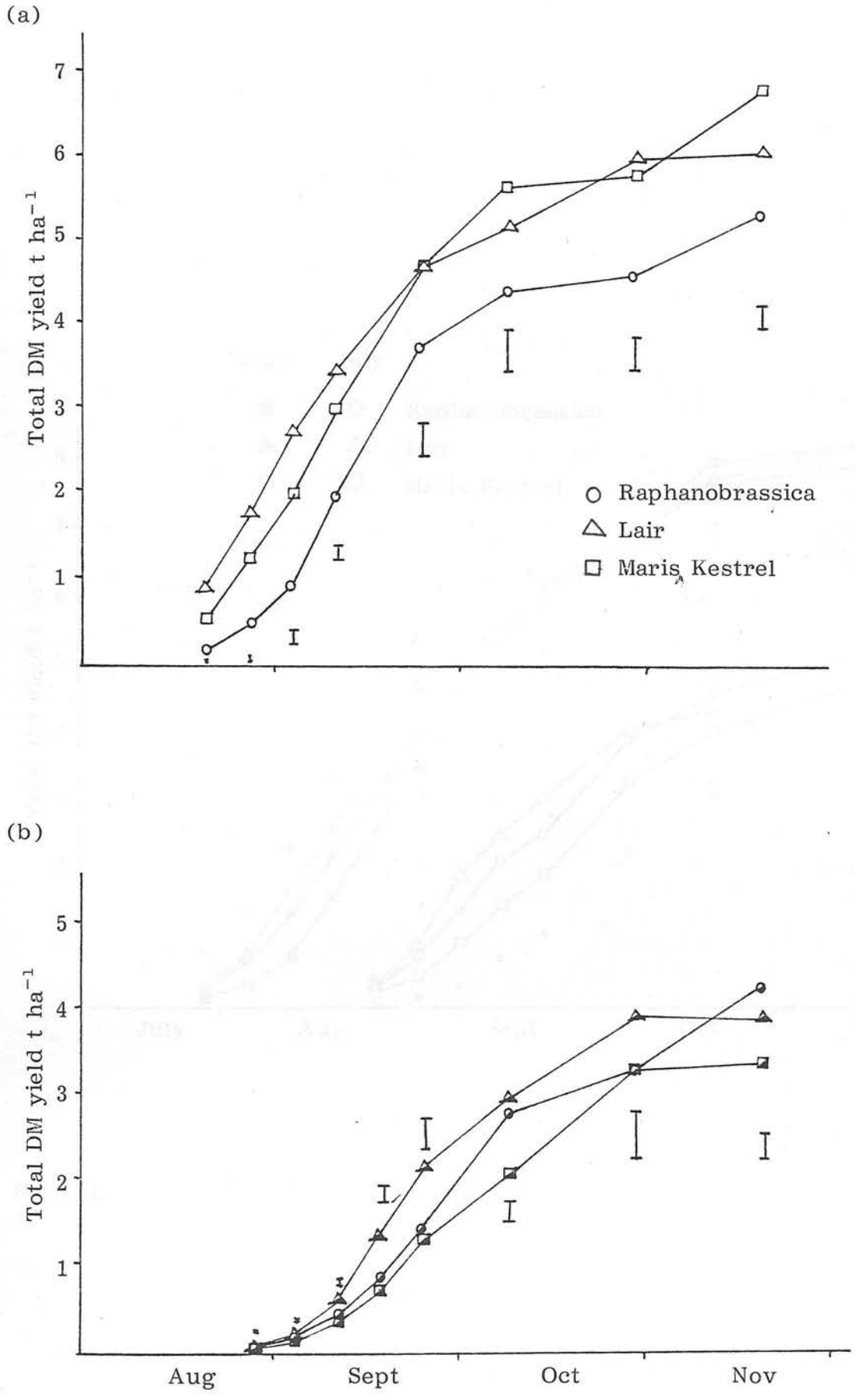


FIGURE 4.2.3: Total dry matter yield 1979. (a) second sowing (late July); (b) third sowing (early August).

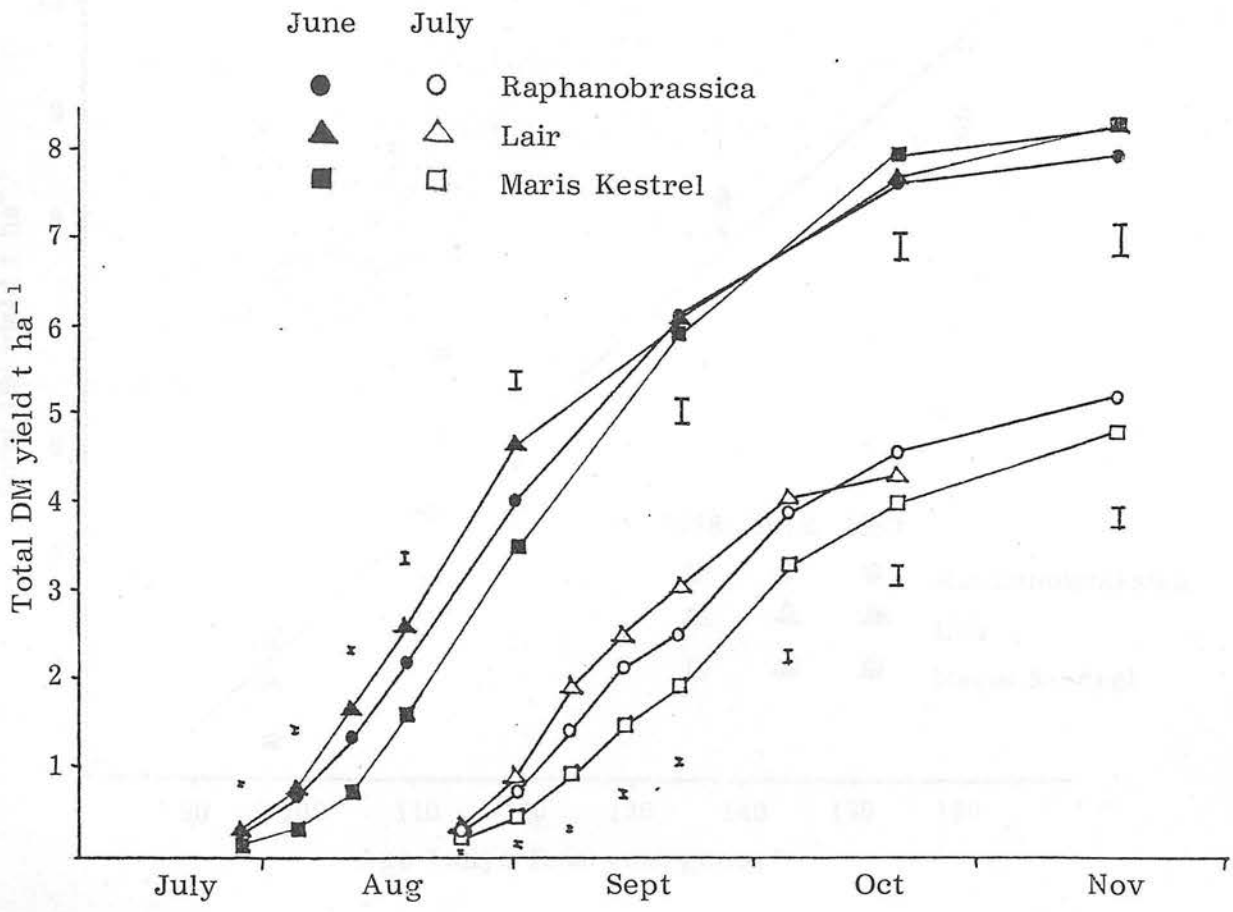


FIGURE 4.2.4: Total dry matter yield 1980.

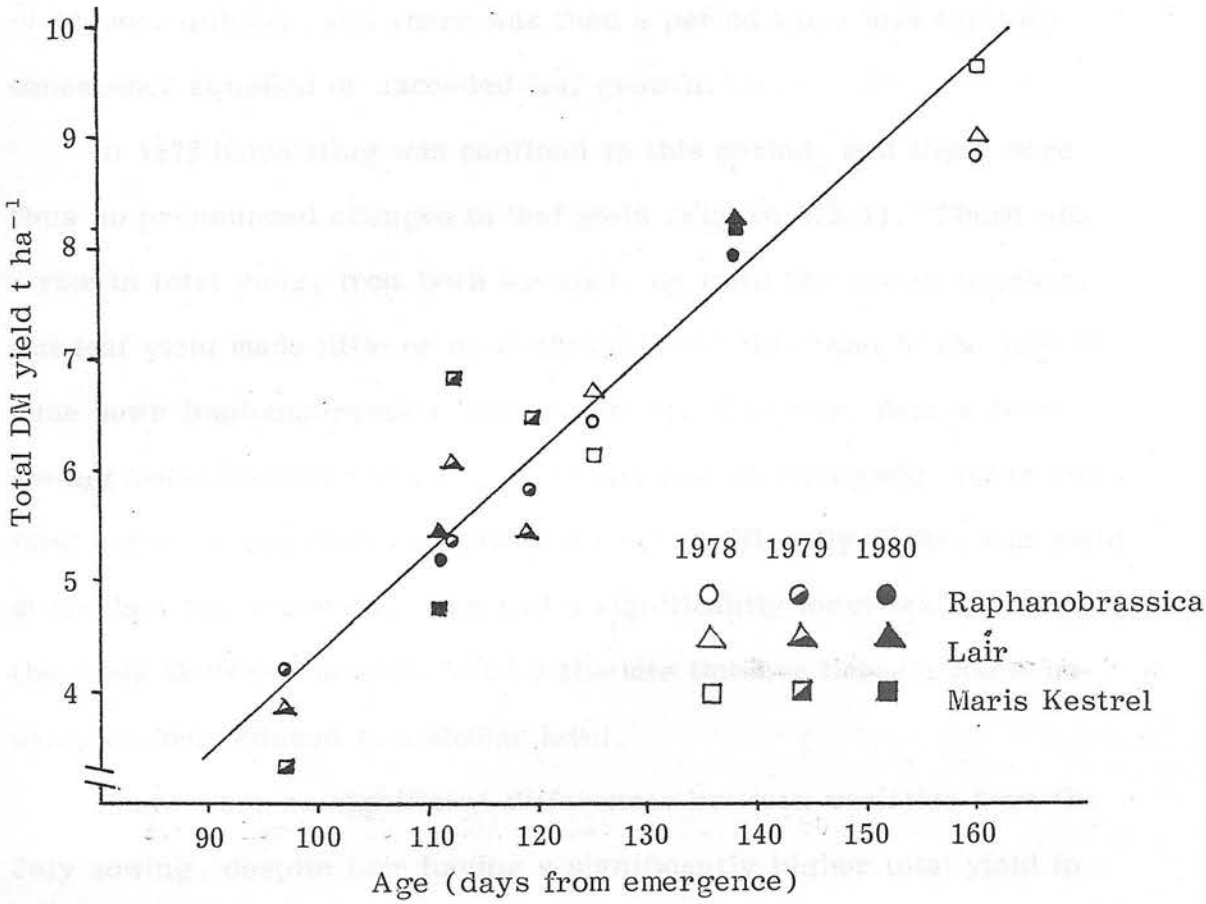


FIGURE 4.2.5: Total dry matter yield. Regression of all treatment against age (days from emergence).

4.3 Leaf Dry Matter Yield

Total dry matter yield was separated into three components - leaf, petiole and stem - to determine and compare the distribution of dry matter throughout the season. The leaf growth curves were similar to those of total yield, in being sigmoidal, but reached an asymptotic yield more quickly, and there was then a period when loss through senescence equalled or exceeded leaf growth.

In 1978 harvesting was confined to this period, and there were thus no pronounced changes in leaf yield (Figure 4.3.1). There was a rise in total yield, from both sowings, up until the end of October, but leaf yield made little or no contribution to this, and in the case of June sown Raphanobrassica, was declining. However, from a June sowing Maris Kestrel showed a continued rise in total yield, up to the final harvest, and this was reflected in a significantly higher leaf yield at the last two harvests. Lair had a significantly lower leaf yield at the early October harvest, but by the late October harvest Raphanobrassica had reduced to a similar level.

There were no significant differences between varieties from the July sowing, despite Lair having a significantly higher total yield in early October. Raphanobrassica had the highest leaf yield over the last three harvests, in contrast to the June sowing, suggesting that the decline in leaf yield shown by June sown Raphanobrassica in October was related to its flowering.

The differences in leaf yield between sowing dates were small, and were only significant for Raphanobrassica and Maris Kestrel at the early October harvest and Maris Kestrel at the late November harvest. There was a 30-35% difference in the final total yields of the two sowing dates, for all varieties, but only with Maris Kestrel were the leaf yield

differences of the same order. The difference in final leaf yields of Lair and Raphanobrassica was less than 0.2 t ha^{-1}.

The 1979 field trial results show the whole of the leaf growth curves (Figures 4.3.2 and 4.3.3). As in total yield, Lair showed an early superiority in leaf yield, from all three sowings, but from the first two sowing dates there was an abrupt cessation of leaf growth, six and eight weeks from emergence respectively. These points correspond with, and thus could account for, the time of reduction in overall growth rate. The third sowing of Lair does not show the sudden halt in leaf growth. However, from the first two sowings it occurred at a leaf yield level of 2 t ha^{-1}, a level which was not attained from the August sowing.

As a consequence of Lair's leaf growth pattern, from the first and second sowing it started the season with the significantly highest leaf yields, and ended it with the significantly lowest. This was most marked from the first sowing, where the high growth rate of Raphanobrassica continued until late September, giving it a leaf yield advantage of 1 t ha^{-1}, or 50% over Lair.

From the second sowing Raphanobrassica had a low population density, but even so it had compensated in leaf yield by the end of September, and had a yield significantly higher than Lair by the final harvest. This was despite having a significantly lower total yield. From the third sowing Raphanobrassica again had a significantly higher final leaf yield, and showed continued growth up until the final harvest.

From the first sowing Maris Kestrel had the lowest initial leaf yields, but sustained its growth rate longer than Lair, though not at such a high rate as Raphanobrassica. It thus ended the season with a leaf yield intermediate between Raphanobrassica and Lair. This compares

with the 1978 July sowing, where Maris Kestrel had the lowest yield at all but the December harvest, though the differences were not significant.

From the second sowing Maris Kestrel had a similar growth pattern, though Raphanobrassica, with its low population density, had the lowest early yields. From the August sowing Maris Kestrel at all times had the lowest leaf yield, but only significantly lower than Raphanobrassica, at two harvests, the sixth and eighth.

As with total yield, similarity in the leaf yield curves from the three sowings was evident. The difference in final yields of Lair was less than 0.3 t ha^{-1}, with the second sowing having the greatest leaf yield. The range in final leaf yields of Raphanobrassica was less than 0.4 t ha^{-1}, but the third sowing of Maris Kestrel had a leaf yield 0.8 t ha^{-1} lower than that of the second sowing.

Thus delaying sowing until as late as early August did not appreciably reduce final leaf yields, although considerably reducing total yield. This was a similar result to that obtained in the 1978 trial, with two earlier sowings.

In 1980 the early growth advantage of Lair over Raphanobrassica was not so apparent, from either sowing date (Figure 4.3.4). The sudden halt in Lair's leaf growth again occurred, but at a later date in the season than in 1979. This matched the pattern of total growth, which also continued later into the season than in 1979, and there was thus again a period when overall yield was increasing but that of leaf remained constant, or decreased.

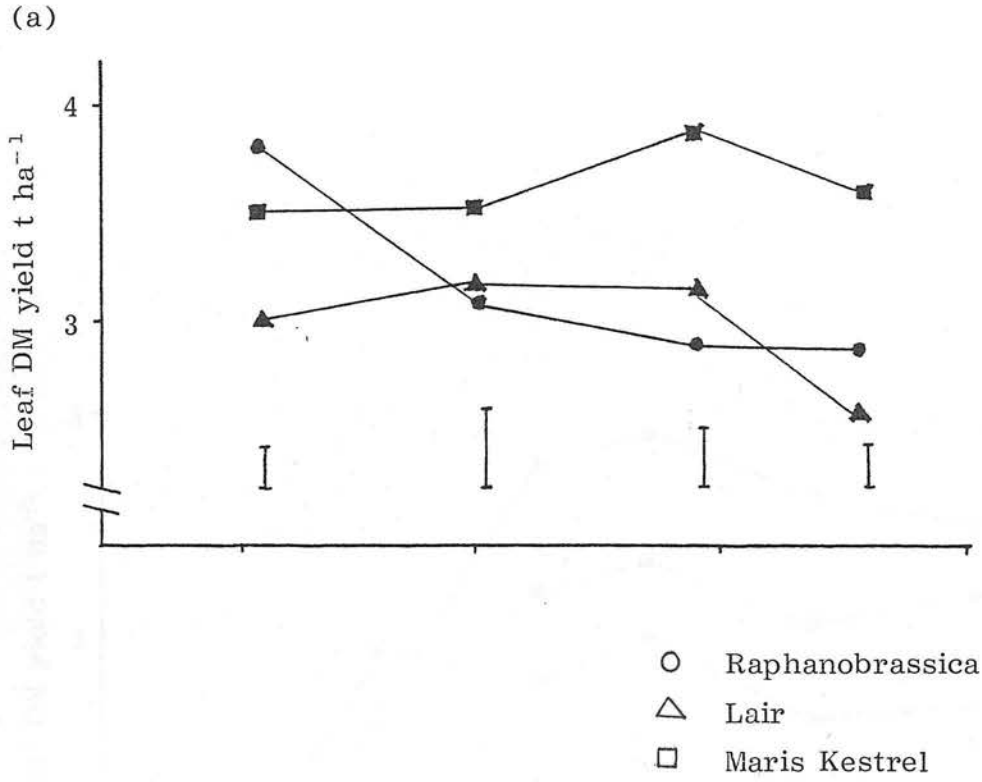
From the June sowing Raphanobrassica leaf growth ceased at the same time as Lair, whilst Maris Kestrel continued to increase for a further month. There were thus no significant differences in final leaf yields.

This was in contrast to the first sowing in 1979, when Raphanobrassica continued its leaf growth later into the season than Lair, giving it a large yield advantage. One explanation is that the expression of flowering, which occurred in 1980, but not in 1979, suppressed leaf production. On the other hand the yield levels attained by Raphanobrassica in 1980 were almost as great as those in 1979, of nearly 3 t ha^{-1}.

From the July sowing the leaf yields of Raphanobrassica were significantly higher at the sixth and seventh harvests, though not the final one, due to the continued growth of Maris Kestrel later in the season. This again compensated for the significantly lower early leaf yields of Maris Kestrel.

The leaf growth patterns of the two sowing dates were again similar, particularly over the early part of growth, and the final yields again fell within a narrow range, 2.1 - 2.7 t ha^{-1}, despite the differences in final total yields.

Final leaf yields were not only similar between sowing dates at each trial, but also between seasons, most notably for Raphanobrassica and Lair, and less so with Maris Kestrel. The three trials encompassed a ten week range in sowing date, and an inevitable variation in growing conditions, and produced final total yields that ranged from 3.5 - 10.5 t ha^{-1}. Nonetheless the total range in leaf yield was only 1.5 - 3.9 t ha^{-1}, and only 1.75 - 3.10 t ha^{-1} if Maris Kestrel is excluded.



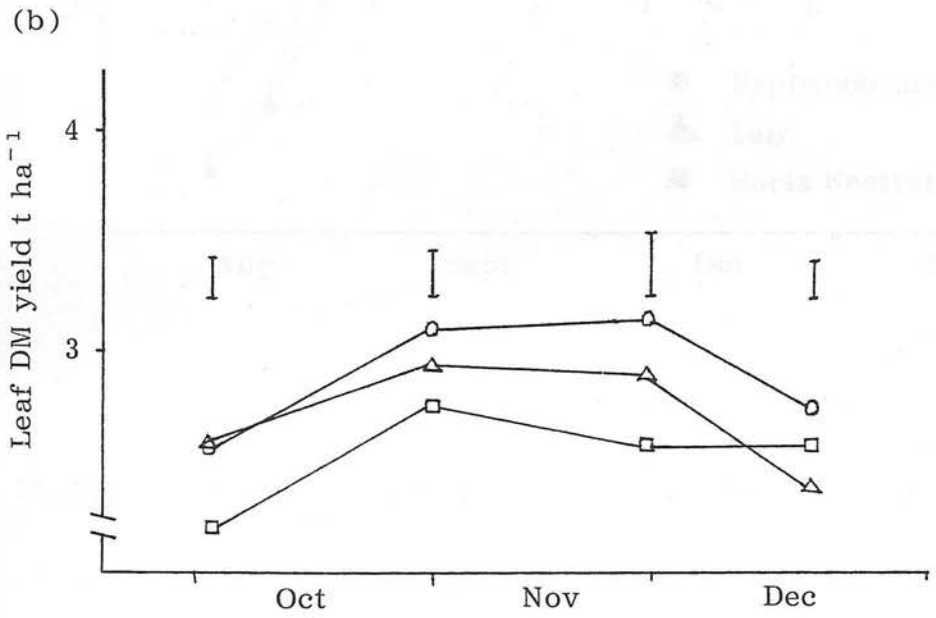


FIGURE 4.3.1: Leaf dry matter yield 1978. (a) June sowing; (b) July sowing.

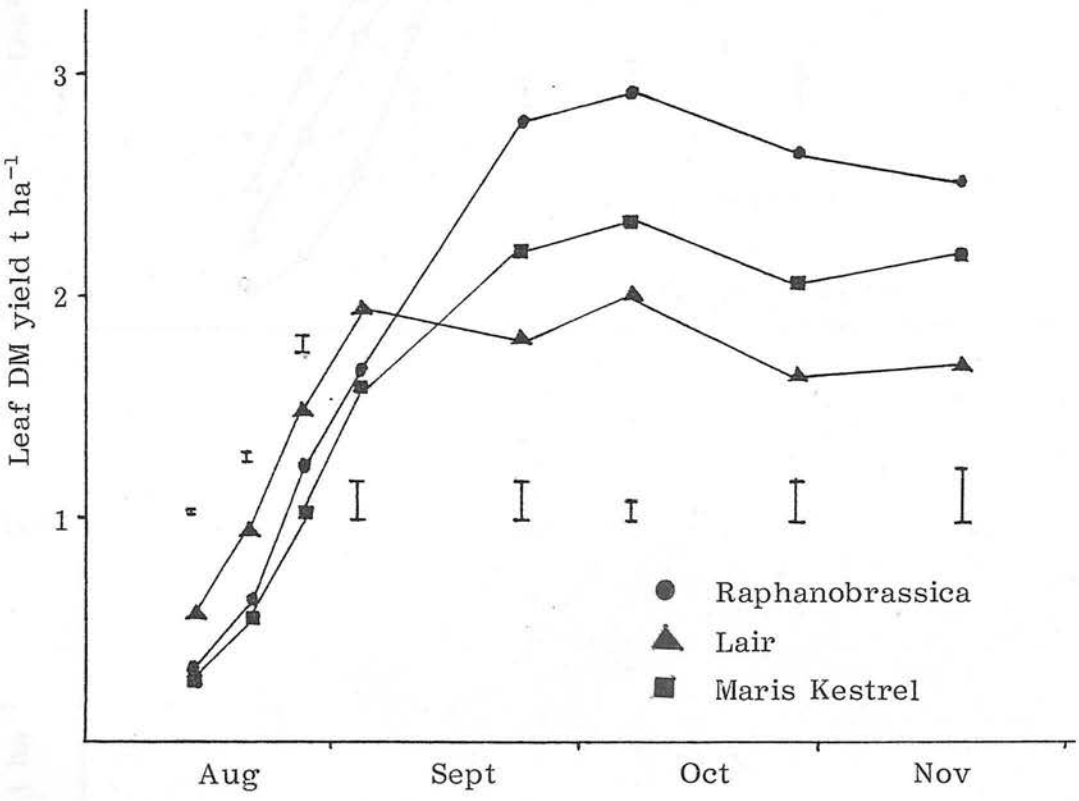


FIGURE 4.3.2: Leaf dry matter yield 1979. First sowing date (early July).

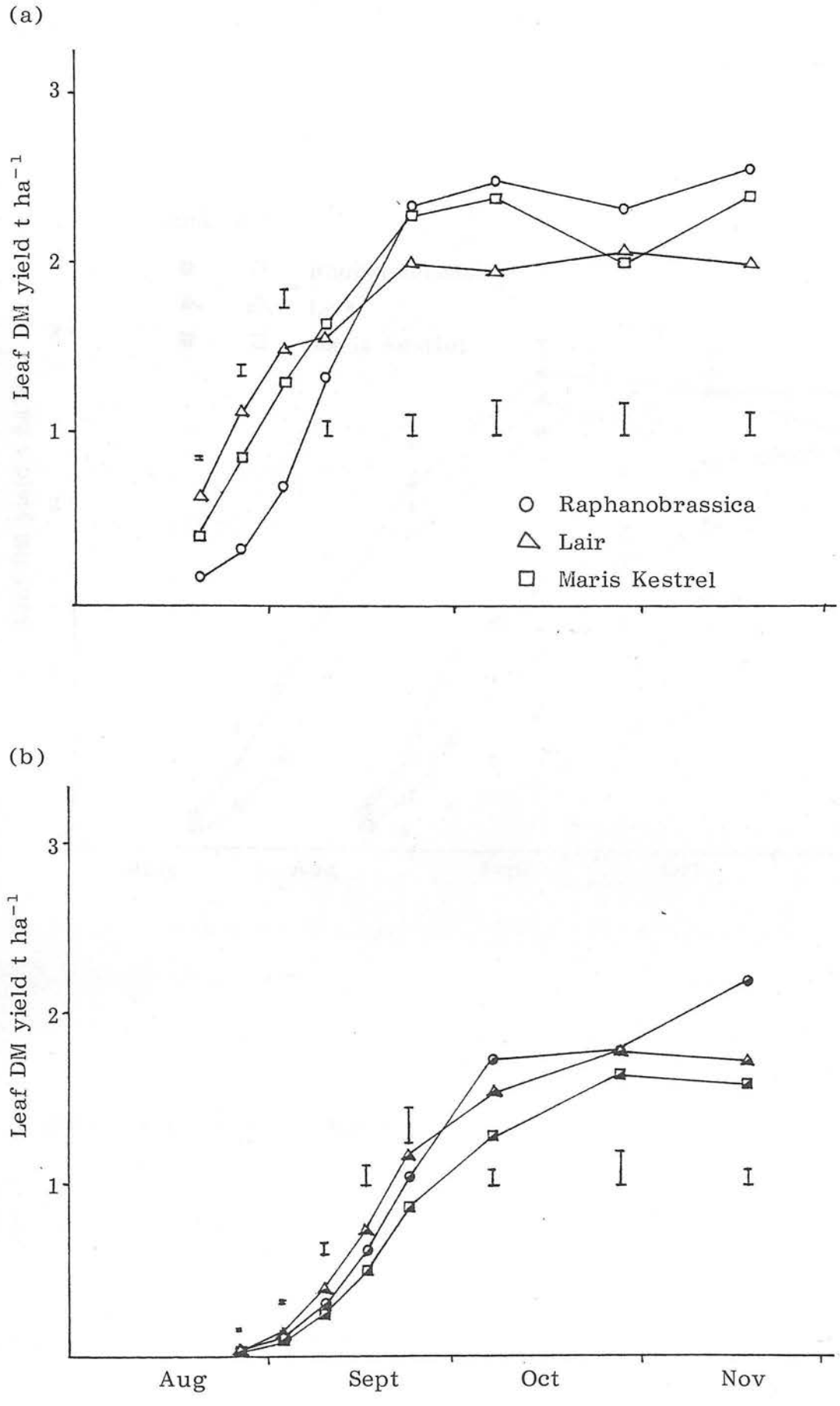


FIGURE 4.3.3: Leaf dry matter yield 1979. (a) second sowing (late July); (b) third sowing (early August).

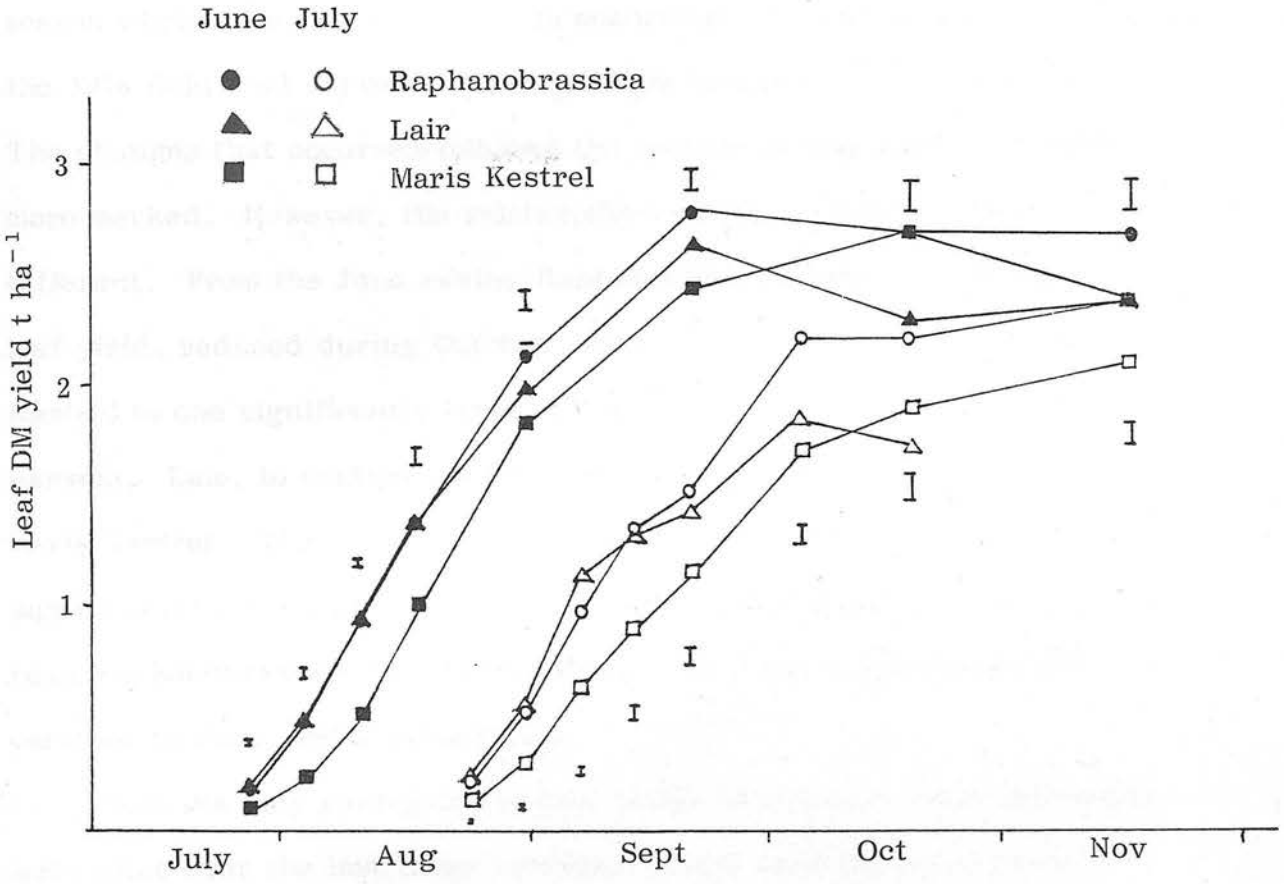


FIGURE 4.3.4: Leaf dry matter yield 1980.

4.4 Petiole Dry Matter Yield

The petiole growth curves were also of a sigmoidal type, and followed the pattern of leaf growth in being flatter than the curves for total growth, i.e. having a longer period during the latter half of the season when little or no growth was occurring. As with leaf yield, the 1978 field trial harvests were all within this period (Figure 4.4.1). The changes that occurred followed the pattern of leaf yield, but were more marked. However, the relationships between varieties were different. From the June sowing Raphanobrassica petiole yield, like leaf yield, reduced during October, from a yield above that of Maris Kestrel to one significantly lower at the next harvest, and also the final harvest. Lair, in contrast to leaf, had a petiole yield comparable to Maris Kestrel. This was until the final harvest, when it reduced to a significantly lower yield. Lair had a petiole yield significantly higher than Raphanobrassica over the final three harvests, and this was in contrast to their similar total yields.

From the July sowing the petiole yields of Lair and Raphanobrassica were close over the last three harvests, whilst from the early October harvest Lair had a significantly higher yield, contributing to its significantly higher total yield at this harvest. Maris Kestrel, at the early October and November harvests, had a significantly lower petiole yield than Lair and Raphanobrassica. This was in contrast to leaf yields, which were not significantly different.

As with leaf, petiole yields did not differ greatly between sowing dates, and Maris Kestrel showed the greatest reduction in yield from a later sowing. Raphanobrassica, over the last three harvests, had a petiole yield greater from the July sowing than from the June sowing, which could represent a flowering effect.

The 1979 field trial results showed a pattern similar to that of leaf growth (Figures 4.4.2 and 4.4.3). Lair again had the initial yield advantage, even more markedly than with leaf, from all three sowings. From the first sowing, petiole growth continued until late September, whereas leaf growth stopped at the beginning of September. However, total growth continued until early October, so there was still a short period when both leaf and petiole yields were declining whilst total yield increased. From the second sowing Lair petiole growth again continued for a few weeks longer than that of leaf, but this time more closely followed the pattern of total growth, as was also the case with the third sowing.

Raphanobrassica, from the first sowing, produced a similar relatively high peak, in early October, in petiole yields, to leaf, and had a significantly higher petiole yield than the other two varieties over the last three harvests. From the second sowing it started the season with a lower yield, due to its low population density, but had compensated by the end of September, as it did in leaf yield. There were no significant differences between varieties in petiole yield over the final four harvests of the second sowing. From the third sowing Raphanobrassica had a significantly higher petiole yield at the final harvest, due to its continued growth in November. These contrast with the 1978 results, when Raphanobrassica had petiole yields similar to, or lower than Lair.

Maris Kestrel had the lowest initial petiole yields from the first sowing, but was similar to the yield of Lair by early October. This was later than with leaf yield, which reached the same level as Lair by early September. The petiole yield of Maris Kestrel was similar to that of Lair over the final three harvests, which contrasts with the 1978 July sowing, when Maris Kestrel had a lower yield than Lair.

From the second sowing Maris Kestrel had intermediate early petiole yields, due to Raphanobrassica's poor performance. Over the last four harvests there were no significant differences, but Maris Kestrel had the lowest yields. From the third sowing Maris Kestrel at all times had the lowest petiole yields, significantly so at the final harvest.

The similarity in growth pattern of the petiole, between sowing dates, was even more marked than with leaf. Only the first sowing of Raphanobrassica and the third sowing of Maris Kestrel deviated from a narrow range in petiole yields throughout the season.

The 1980 field trial results showed the same petiole growth patterns (Figure 4.4.4). From the June sowing petiole growth rate started to decline from the beginning of September, although the petiole yield did not reach a maximum until late October. This was in contrast to leaf growth, which ceased at the end of September, and total growth, which continued until late October. From the July sowing petiole yield continued to increase to the end of the season.

Lair had the highest earlier yields from both sowings, in contrast to leaf yield, where Lair and Raphanobrassica had similar early yields. Maris Kestrel had the lowest early yields, and Raphanobrassica was intermediate.

From the June sowing all three varieties had similar yields by the end of September, and there were no significant differences over the last three harvests. This contrasts with leaf yield, where Raphanobrassica had higher late season yields than Lair, significantly so at the seventh harvest, and also the first sowing of the 1979 trial, where Raphanobrassica produced a significantly higher petiole yield over the last three harvests. This difference could again be due to flowering of Raphanobrassica in the 1980 trial.

From the July sowing Lair maintained its early advantage in petiole yield throughout the season, and the yield of Maris Kestrel was depressed significantly below those of the other two varieties throughout the season. This pattern was similar to the results for the 1979 August sowing, and was again in contrast to the compensations that occurred in leaf yield.

The similarity of early petiole growth rates at each sowing was even more marked than with leaf. With Lair and Raphanobrassica this similarity continued throughout the season. With Maris Kestrel, after the first four harvests when yields were similar, the June sowing then had a higher growth rate to the end of the season.

With the exception of late sown Maris Kestrel, the final petiole yields of all three trials were within a very small range, 1.25 - 2.25 t ha^{-1}. Thus, as with leaf yield, both sowing date and season had little effect on final yield of petiole.

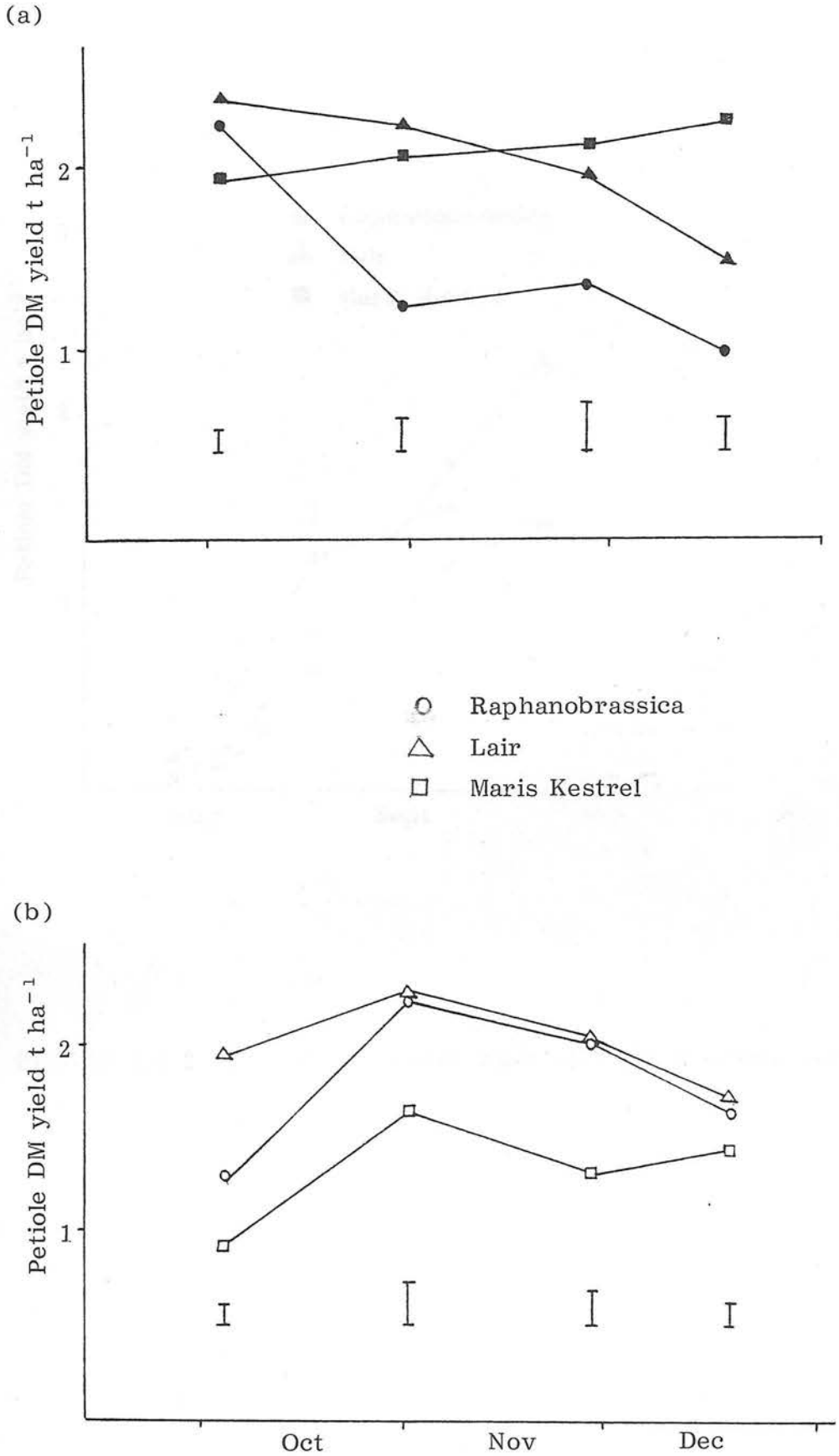


FIGURE 4.4.1: Petiole dry matter yield. (a) June sowing; (b) July sowing.

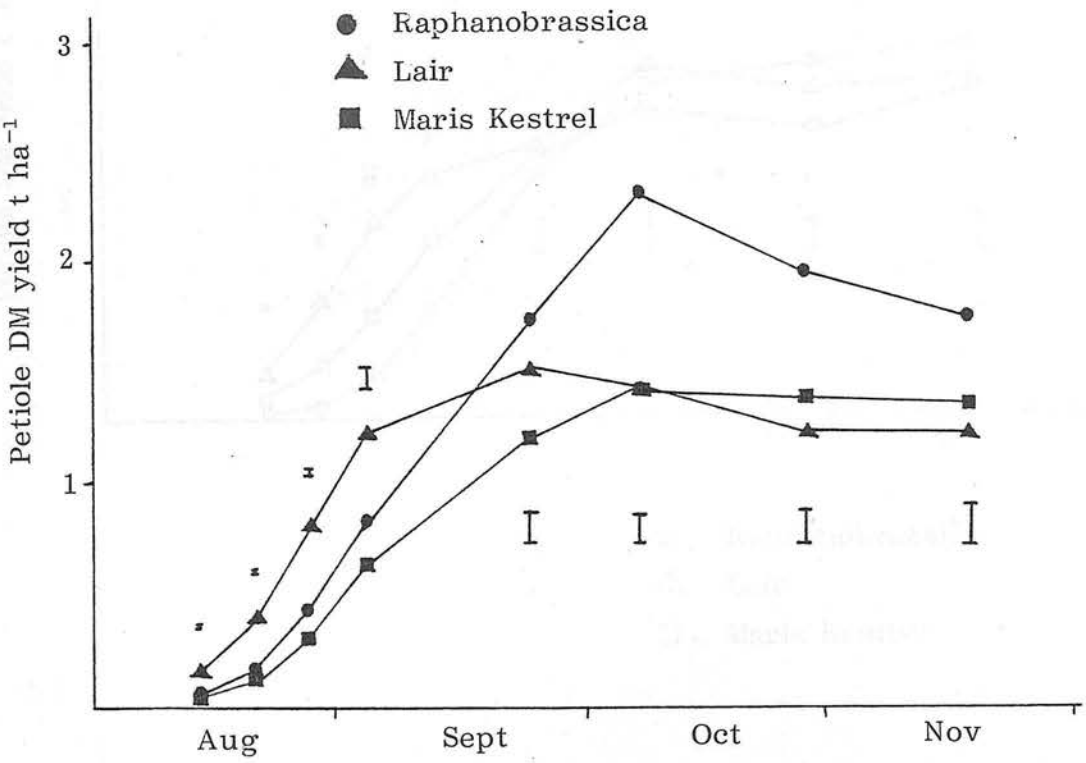


FIGURE 4.4.2: Petiole dry matter yield 1979. First sowing (early July).

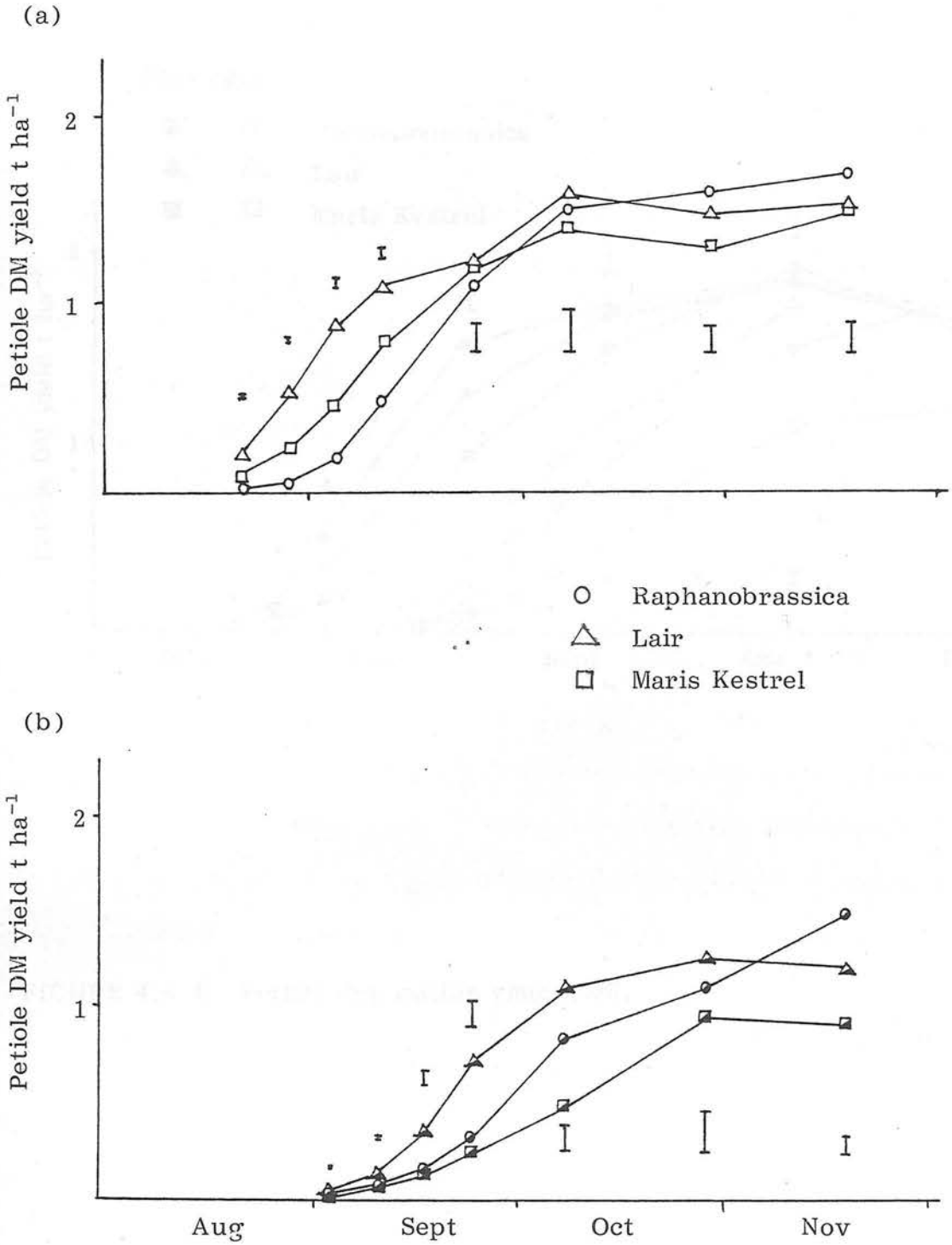


FIGURE 4.4.3: Petiole dry matter yield. (a) second sowing (late July); (b) third sowing (early August).

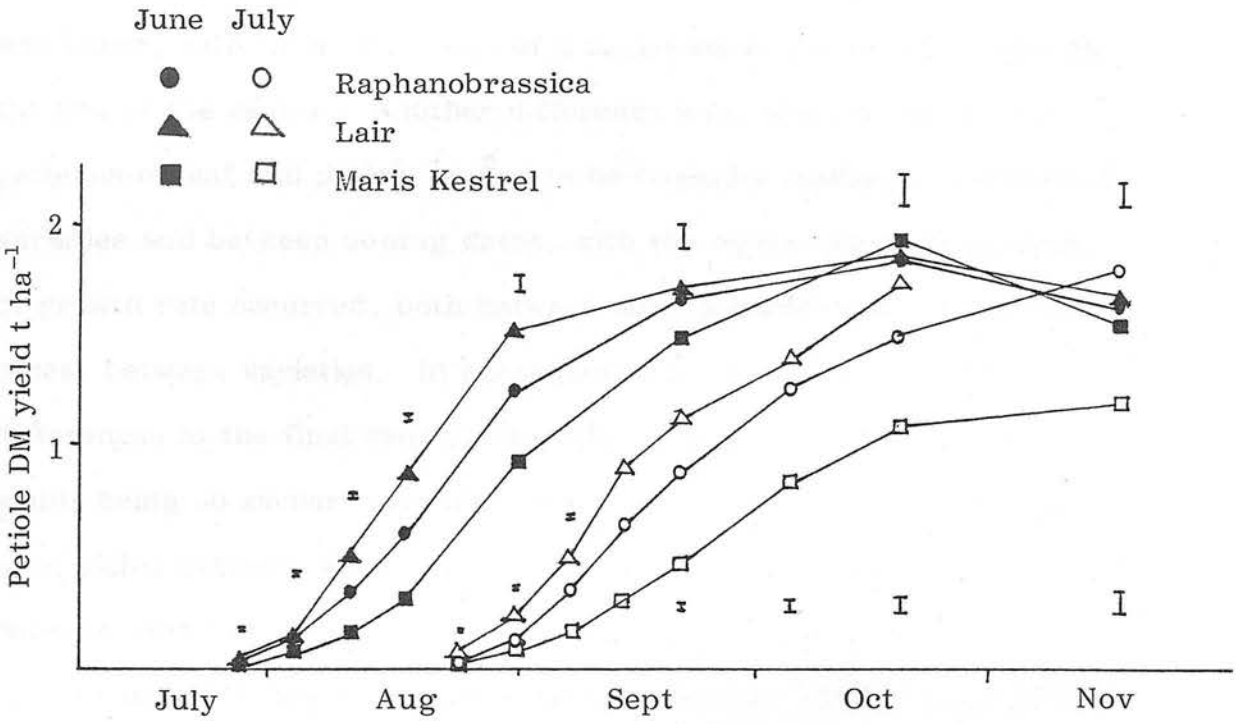


FIGURE 4.4.4: Petiole dry matter yield 1980.

4.5 Stem Dry Matter Yield

The final component of total yield, the stem, showed a different pattern of growth to leaf and petiole. There was an initial short period of exponential growth, but through most of the season growth was linear, with little or no sign of a reduction in growth rate towards the end of the season. Another difference was, whereas the growth patterns of leaf and petiole tended to be basically similar, both between varieties and between sowing dates, with the stems, large differences in growth rate occurred, both between sowing dates, and, in certain cases, between varieties. In consequence there were substantial differences in the final stem yields, which, with the leaf and petiole yields being so similar, accounted for most of the differences in final total yields between sowing dates, and also much of the difference between varieties.

In the 1978 field trial the harvests were over the later part of the season, and thus showed only the linear period of stem growth (Figure 4.5.1). From the July sowing all varieties showed steady linear growth throughout the harvest period. From the June sowing there was a reduction in growth at the end of October, particularly in Raphanobrassica, which was influenced by flowering, but it then proceeded at a steady rate, similar to that of the July sowing, over the final three harvests.

There were no significant differences between varieties from the June sowing, but Raphanobrassica had the highest yield over the final three harvests, due to its higher growth rate in October. In contrast Raphanobrassica had a significantly lower stem yield at all harvests from a July sowing, another difference that was probably influenced by its flowering response from the June sowing. The stem yields of Lair

and Maris Kestrel were similar from both sowings, and not significantly different at any time.

Over the last three harvests the total yields of Raphanobrassica and Lair were constant or declining, whilst those of Maris Kestrel were increasing slowly. Stem yields were increasing steadily over this period, so the differences in total growth were due to differing rates of decline in leaf and petiole. Thus, although stem yields continued to increase in late autumn, it was at the expense of leaf and petiole yield, particularly with Raphanobrassica and Lair.

The final stem yields were much affected by sowing date. Those of Lair and Maris Kestrel from a June sowing were twice those from a July sowing, and with Raphanobrassica were over three times as great. The final leaf and petiole yields were similar between sowing dates and thus the differences in final total yield were almost entirely made up of stem.

The 1979 trial, covering the whole growth period, showed the short initial period of exponential stem growth, followed by the long, linear phase (Figures 4.5.2 and 4.5.3). From all three sowings the growth patterns of Lair and Maris Kestrel were similar, and in fact their stem yields were only significantly different at two harvests, the final harvests of the first and second sowings. This was a similar result to the 1978 trial.

Raphanobrassica had a consistently lower stem growth rate and hence lower yield. Its stem yield was significantly lower at all harvests of the first and second sowings, and at three harvests from the third sowing. These lower stem yields were compensated for by higher leaf and petiole yields, particularly from the first sowing, which gave Raphanobrassica total yields comparable to the other two varieties.

As in 1978, there were periods at the end of the season when total yield was not increasing, and the increase in stem yield was balanced by a decrease in leaf and petiole yield.

The stem growth rates of the first and second sowing of Lair and Maris Kestrel were almost identical, but the second sowing of Raphanobrassica had a lower growth rate, due to its low population density. The third sowing had much reduced growth rates, producing final stem yields of less than 30% of the previous sowings. As in 1978, differences in stem yield accounted for most of the differences in total yield between sowing dates.

The 1980 trial stem yields followed the same pattern as in the previous seasons (Figure 4.5.4). There was less distinction between Raphanobrassica and the other two varieties, although the final stem yields were significantly different. However, during the early part of the season the yields of Raphanobrassica and Maris Kestrel were similar, whilst Lair had a significantly higher yield, from both sowings.

The flowering of Raphanobrassica from the June sowing did not increase its stem yield above that of Lair and Maris Kestrel as it did in 1978, but the flowering was at a lower level than in that season. However, it could have had the effect of increasing stem yields to a level closer to that of the other two varieties.

There was again a period at the end of the season when stem yield was increasing at the expense of leaf and petiole, but as total yields continued to increase until the end of the season, this was less pronounced.

The stem growth patterns of both sowing dates during the early stages of growth were similar, as were leaf and petiole growth patterns, but only over the first three harvests, after which different linear growth rates were apparent. As a result, the final stem yields from a July sowing

were only 30% of those from a June sowing, which again accounted for most of the total yield differences between sowing dates.

In a similar manner it was stem yields which varied from season to season, and thus controlled between season variation in total yields.

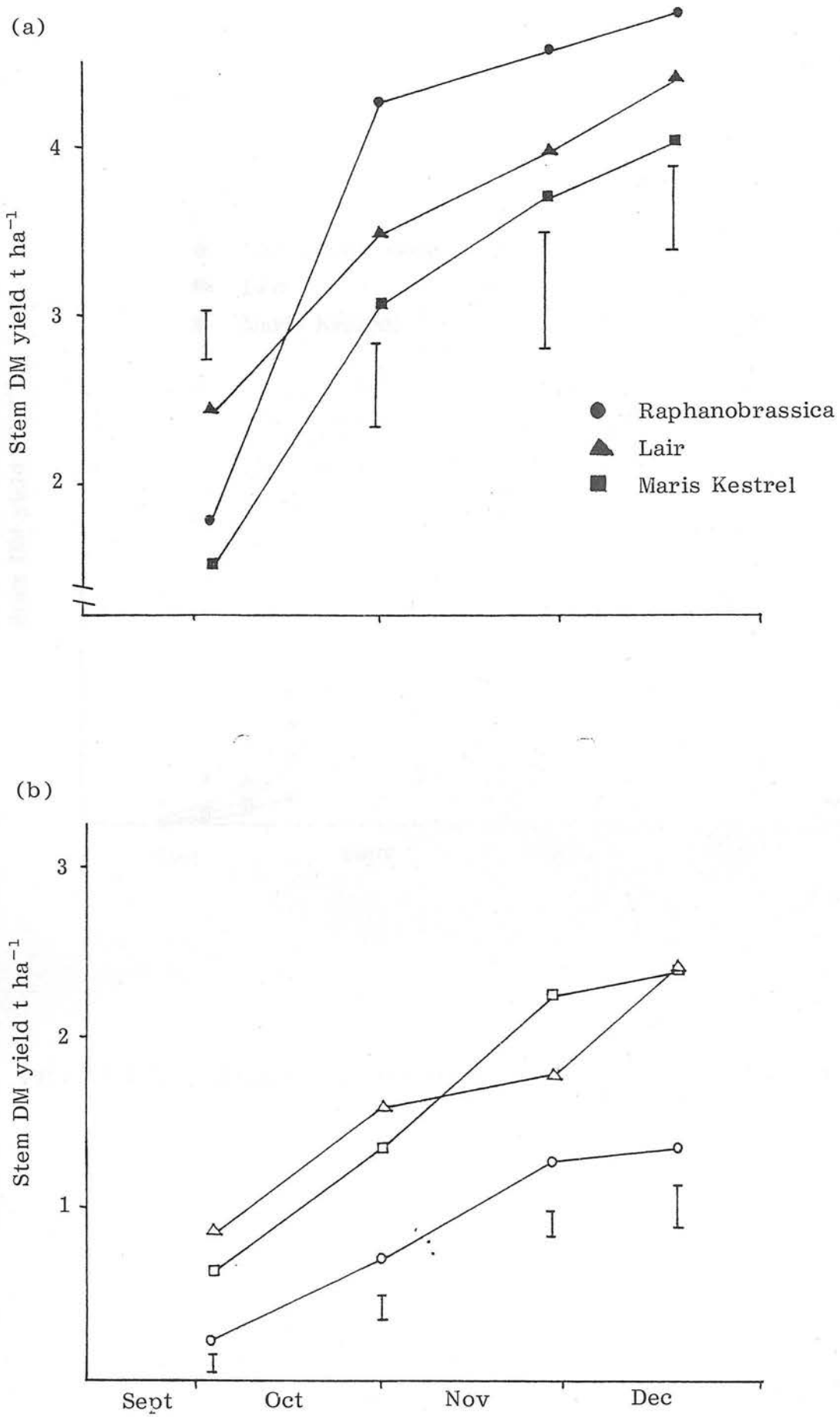


FIGURE 4.5.1: Stem dry matter yield 1978. (a) June sowing; (b) July sowing.

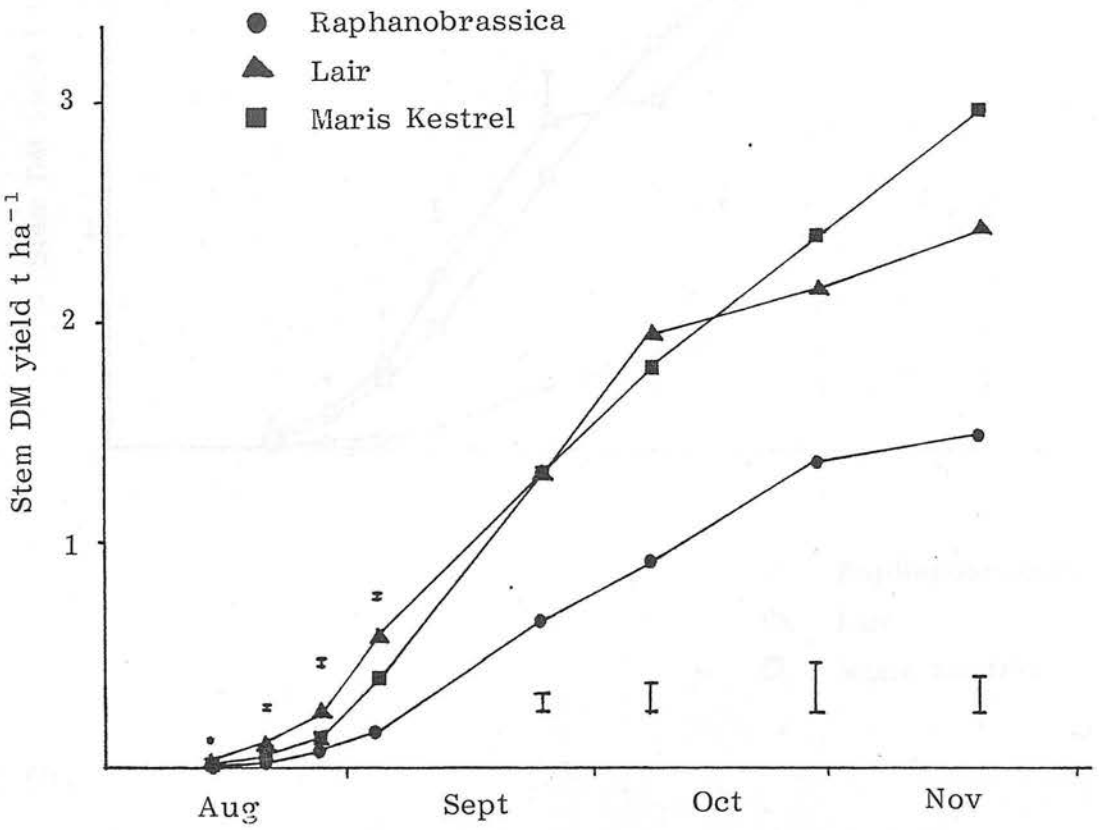


FIGURE 4.5.2: Stem dry matter yield 1979. First sowing (early July).

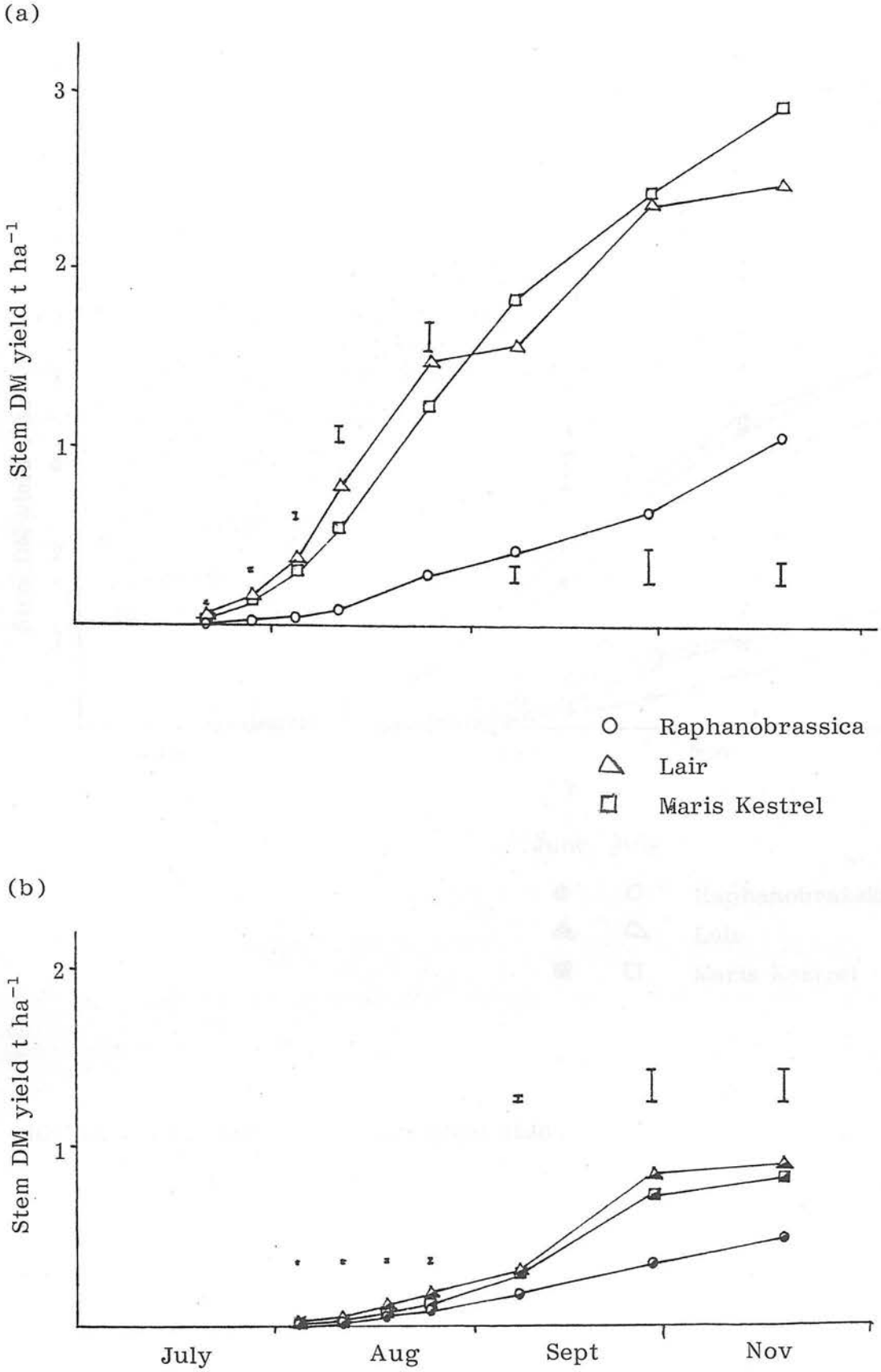


FIGURE 4.5.3: Stem dry matter yield. (a) second sowing (late July); (b) third sowing (early August).

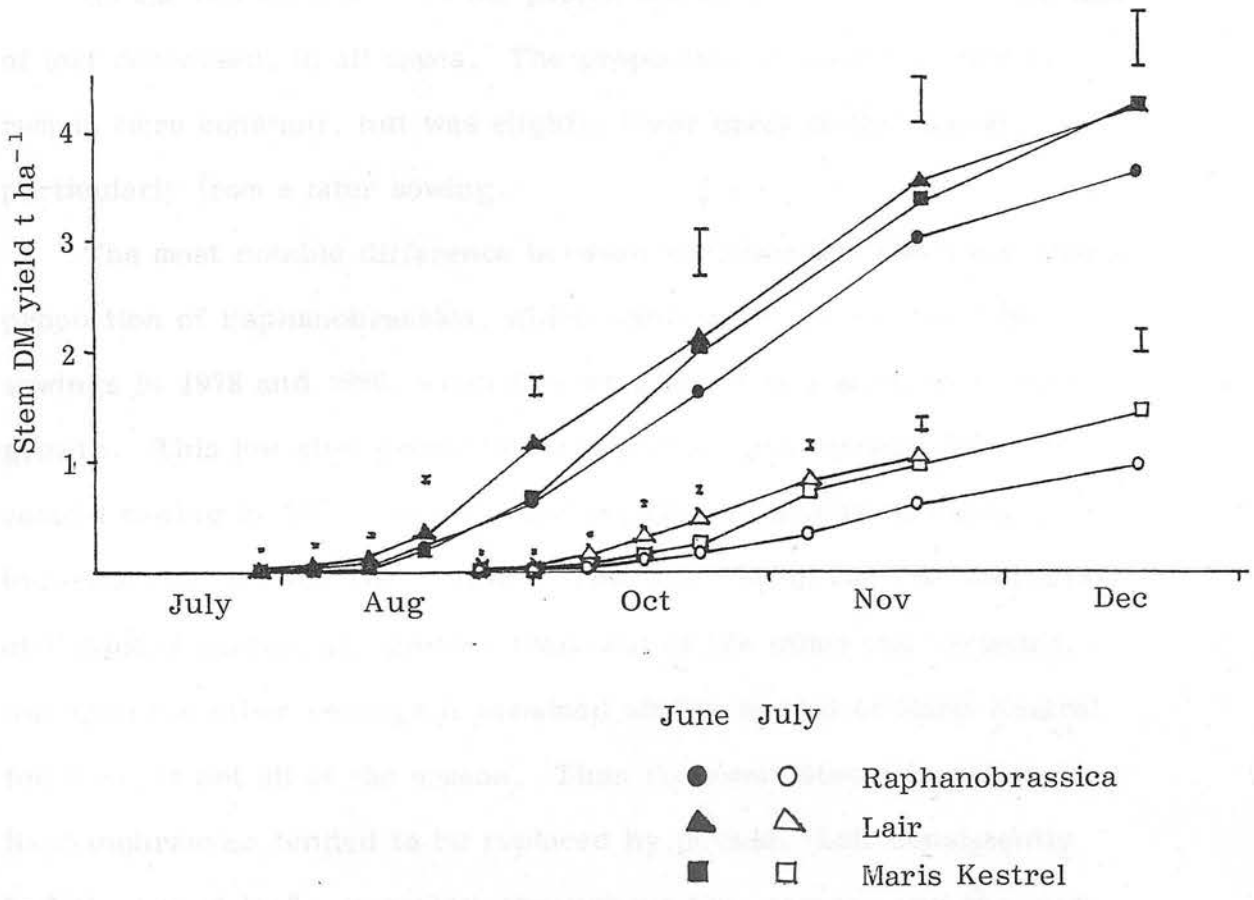


FIGURE 4.5.4: Stem dry matter yield 1980.

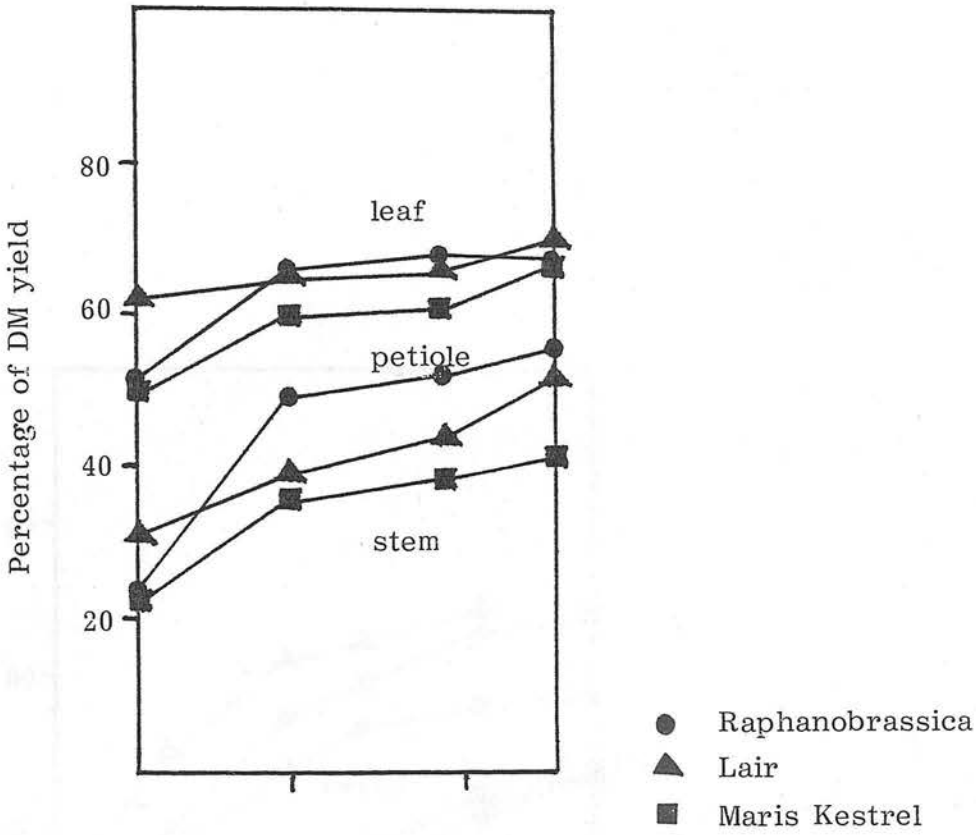
4.6 Partitioning of Dry Matter

The leaf, petiole and stem yields were calculated as percentages of the total dry matter yield, thus revealing the proportion of the total crop in these fractions (Figures 4.6.1 to 4.6.4).

As the season advanced the proportion of stem increased, and that of leaf decreased, in all cases. The proportion of petiole tended to remain more constant, but was slightly lower early in the season, particularly from a later sowing.

The most notable difference between varieties was the lower stem proportion of Raphanobrassica, which occurred at all but the June sowings in 1978 and 1980, when flowering acted as a stimulus to stem growth. This low stem proportion was particularly evident from the second sowing in 1979, when the low population density of Raphanobrassica was an additional factor. From this sowing the leaf proportion of Raphanobrassica was greater than that of the other two varieties, but from the other sowings it remained similar to that of Maris Kestrel for most, if not all of the season. Thus the lower stem proportion of Raphanobrassica tended to be replaced by petiole. Lair consistently had the lowest leaf proportion, throughout the seasons, and the stem proportions of Lair and Maris Kestrel were always similar, though again Lair tended to have the lower proportion. Thus Lair consistently had a higher proportion of petiole in comparison to Maris Kestrel.

(a)



(b)

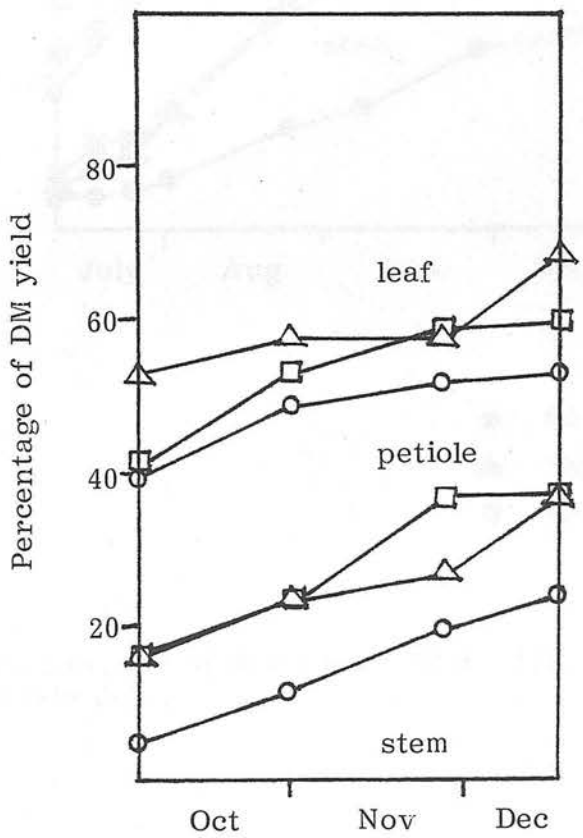


FIGURE 4.6.1: Partitioning of dry matter 1978. (a) June sowing; (b) July sowing.

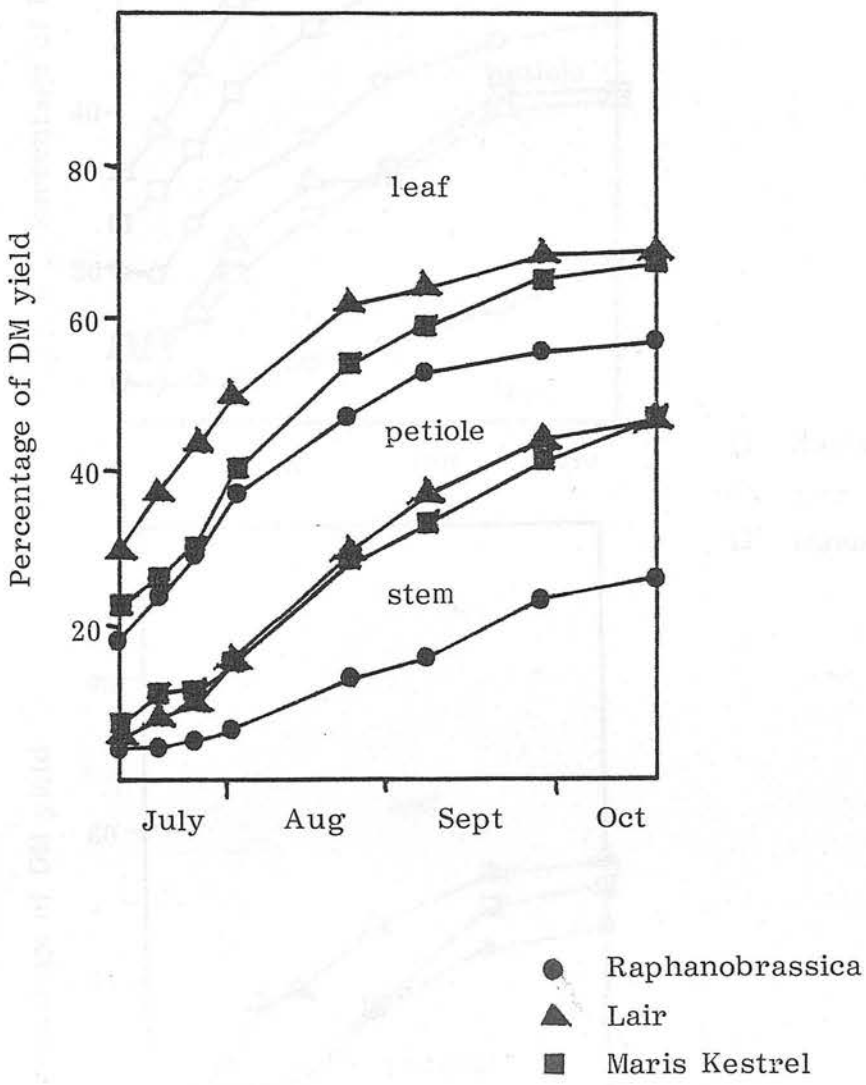
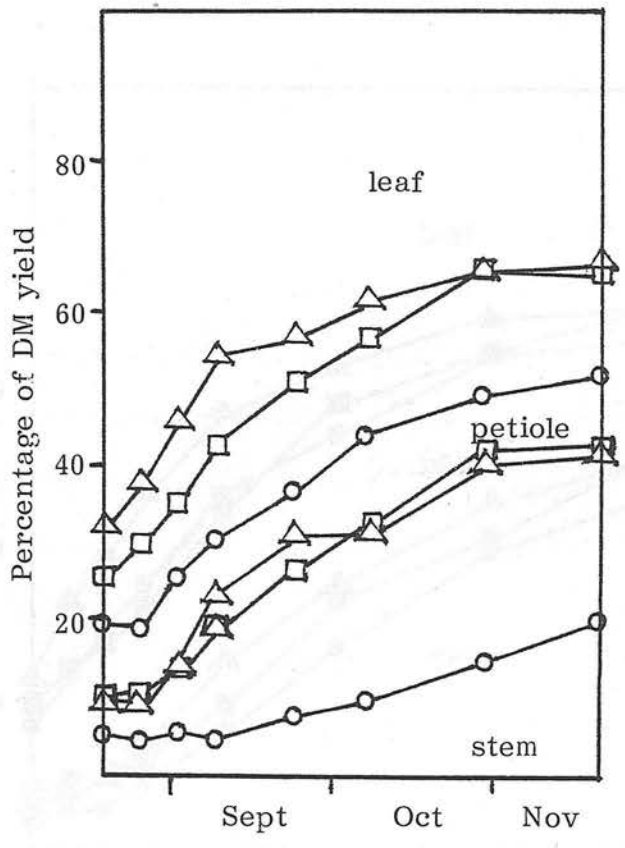
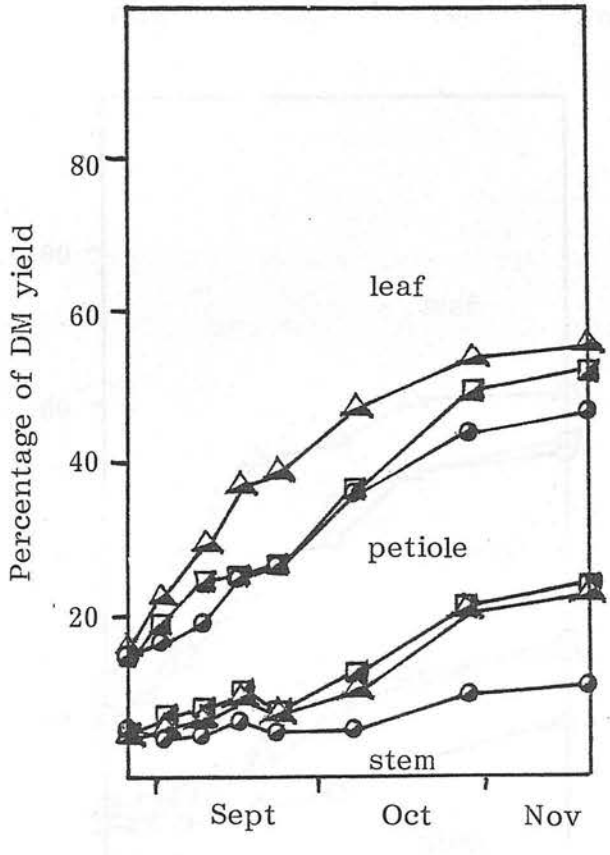


FIGURE 4.6.2: Partitioning of dry matter 1979. First sowing (early July).

(a)



(b)



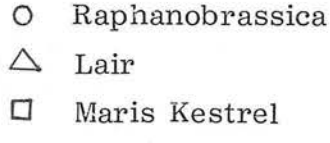
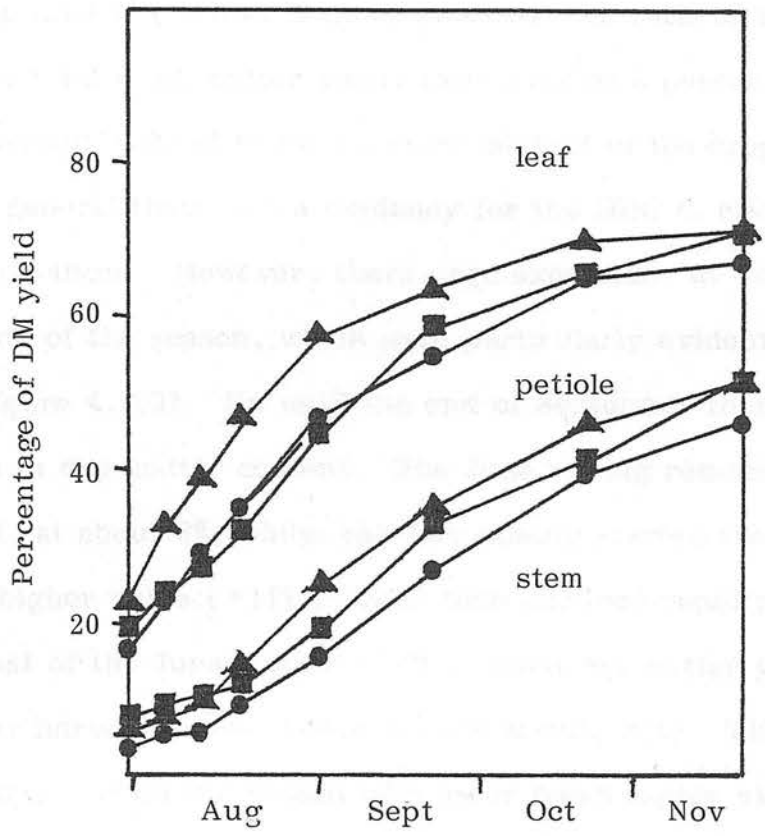


FIGURE 4.6.3: Partitioning of dry matter 1979. (a) second sowing (early July); (b) third sowing (early August).

(a)



(b)

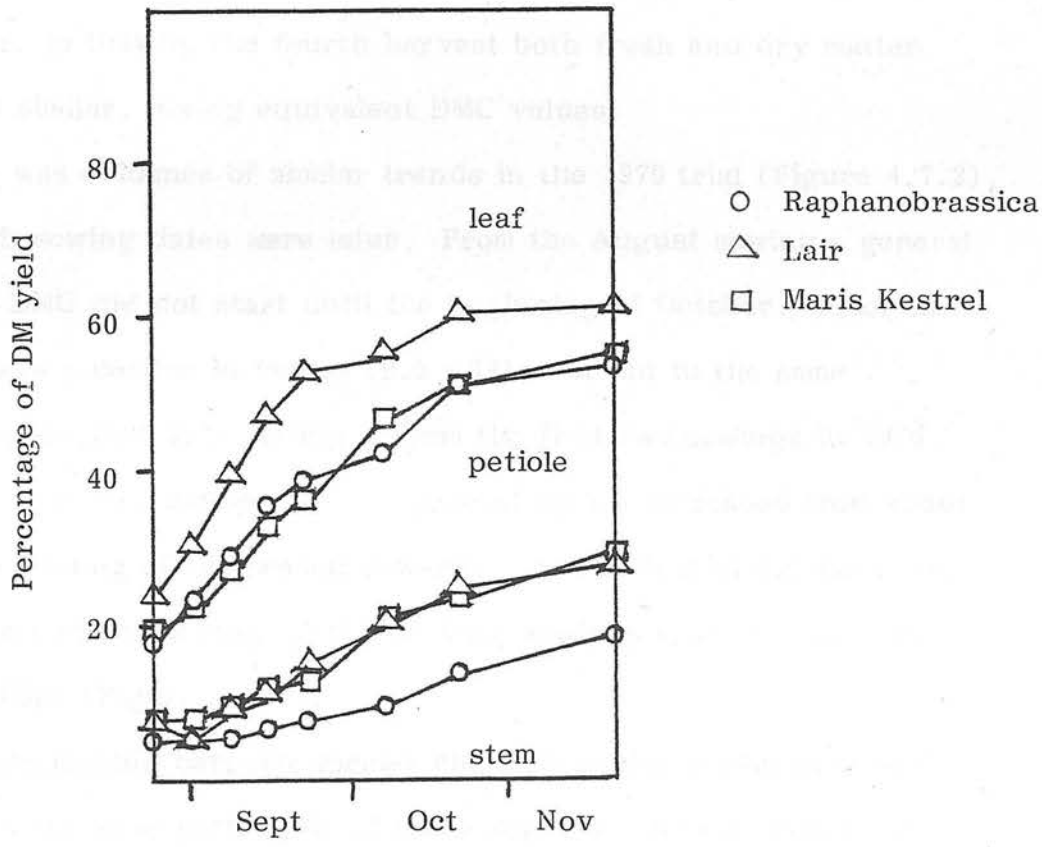


FIGURE 4.6.4: Partitioning of dry matter 1980.

4.7 Total Dry Matter Content

The total Dry Matter Content (DMC) is the ratio of total dry matter to total fresh matter yield, expressed as a percentage. It is thus inversely related to the moisture content of the crop.

In general there was a tendency for the DMC to rise as the season advanced. However, there were exceptions to this, during the early part of the season, which were particularly evident in the 1980 trial (Figure 4.7.3). Up until the end of September there was no marked increase in dry matter content. The June sowing remained relatively constant, at about 8%, whilst the July sowing started the season with a much higher value ($\approx$ 11%), which then declined rapidly to a level below that of the June sowing ($\approx$ 7%). Total dry matter yields over the first four harvests were similar at each sowing date. Thus the July sown crops started the season with lower fresh matter yields than the June sown, at an equivalent age, and then had a higher fresh matter growth rate, so that by the fourth harvest both fresh and dry matter yields were similar, giving equivalent DMC values.

There was evidence of similar trends in the 1979 trial (Figure 4.7.2), even though sowing dates were later. From the August sowing a general increase in DMC did not start until the beginning of October. Prior to this there was a decline in values (9.5 $\rightarrow$ 8%), but not to the same extent as in the 1980 July sowing. From the first two sowings in 1979 there were some fluctuations, but in general values increased from about 8% at the beginning of the season onwards. The 1978 trial did not cover the early part of the season, and from both sowings showed a steadily increasing DMC (Figure 4.7.1).

The relationship between species changed as the season advanced, and followed the same pattern in all three seasons. At the beginning

of the season Maris Kestrel had the highest DMC, Lair the lowest, and Raphanobrassica had the intermediate value. Raphanobrassica maintained a percentage value 1 - 2 below that of Maris Kestrel. Lair, however, had a faster rate of increase than the other two varieties, and ended the season with a higher relative value. The extent of this increase depended on the length of the growing season. Thus, from the June and July sowings in 1978, and the June sowing in 1980, at the final harvest Lair had the highest DMC, but from the other sowings its value was above that of Raphanobrassica, but not as great as that of Maris Kestrel. From the August sowing in 1979 and the July sowing in 1980 Lair had a DMC significantly higher than Raphanobrassica only at the final harvest.

The DMC of the three components of yield, leaf, petiole and stem, were also calculated. These all followed the same pattern as total DMC, with leaf tending to have the highest values, petiole the lowest, with stem values intermediate.

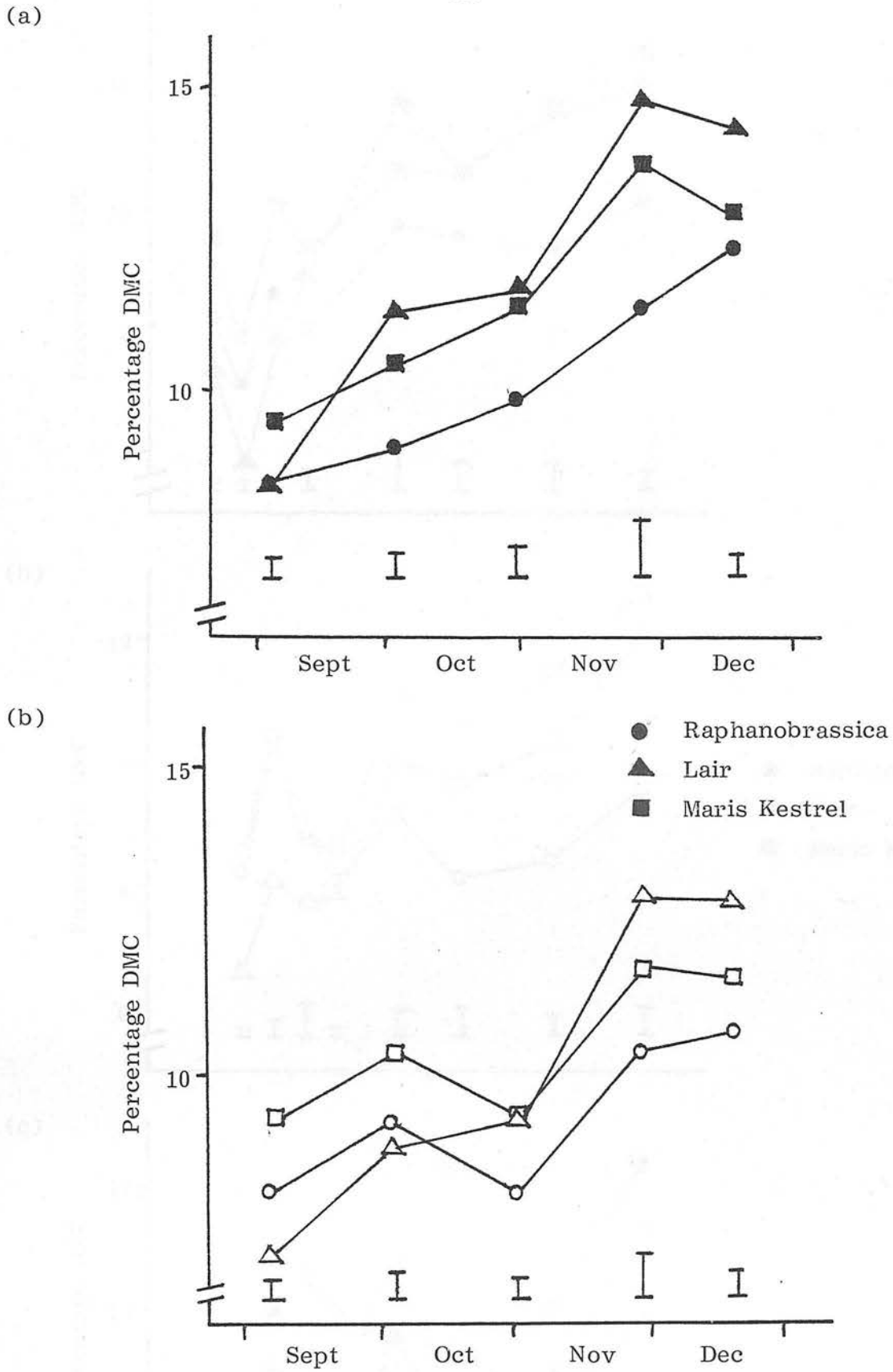


FIGURE 4.7.1: Total dry matter content 1978. (a) June sowing; (b) July sowing.

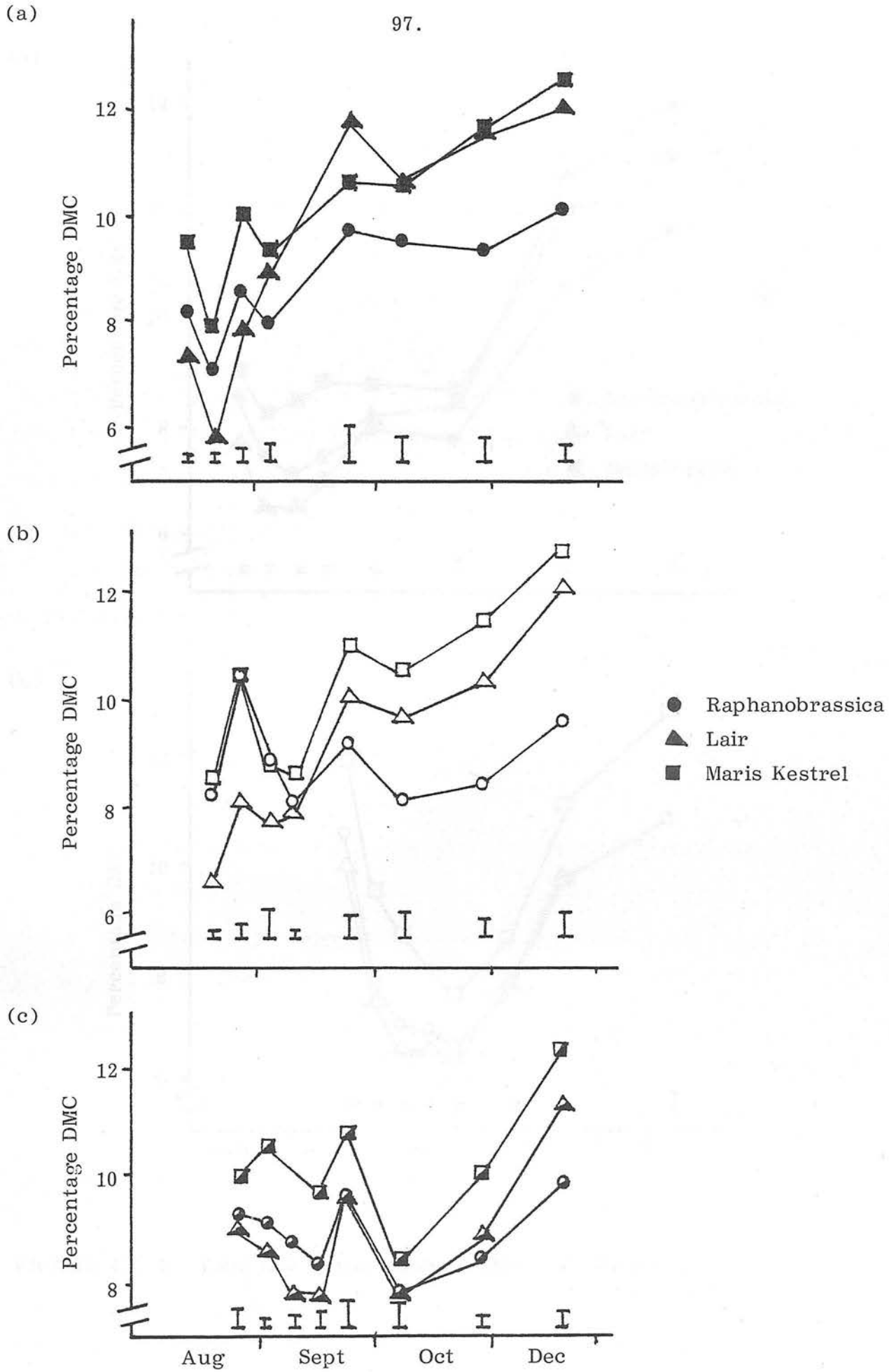


FIGURE 4.7.2: Total dry matter content 1979. (a) first sowing (early July); (b) second sowing (late July); (c) third sowing (early August).

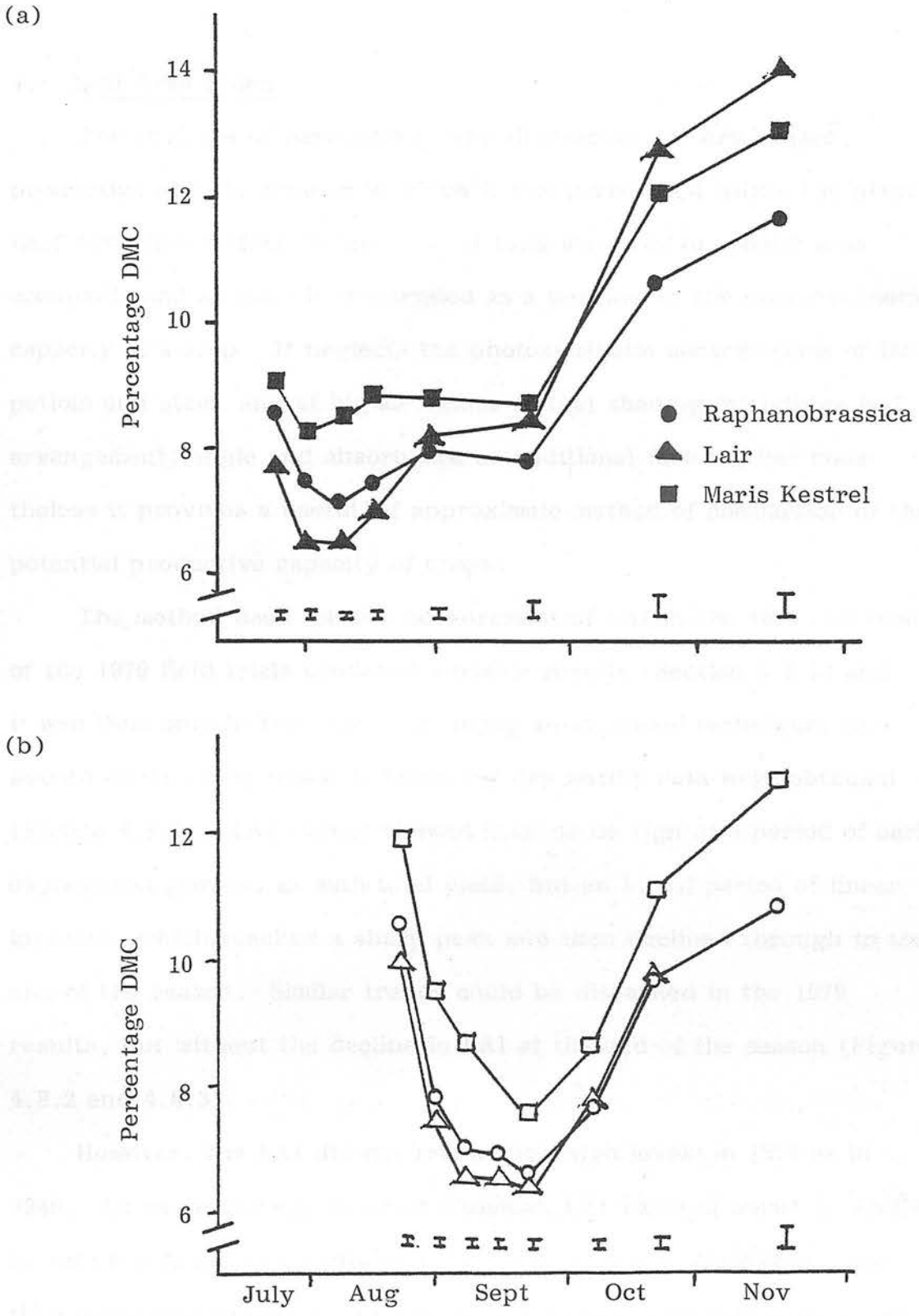


FIGURE 4.7.3: Total dry matter content 1980. (a) June sowing; (b) July sowing.

4.8 Leaf Area Index

The first set of parameters were all measures of dry matter production and the manner in which it was partitioned within the plant. Leaf Area Index (LAI) is the ratio of total leaf area to ground area occupied, and as such it is intended as a measure of the photosynthetic capacity of a crop. It neglects the photosynthetic contributions of the petiole and stem, and at higher values mutual shading introduces leaf arrangement, angle and absorbance as additional factors, but nonetheless it provides a useful, if approximate method of comparison of the potential productive capacity of crops.

The method used for the measurement of LAI in the 1978 and most of the 1979 field trials produced variable results (Section 3.1.5) and it was thus only in the 1980 trial, using an improved technique, that smooth curves comparable to those for dry matter data were obtained (Figure 4.8.4). LAI curves showed little or no sign of a period of early exponential growth, as with total yield, but an initial period of linear increase, which reached a sharp peak and then declined through to the end of the season. Similar trends could be discerned in the 1979 results, but without the decline in LAI at the end of the season (Figures 4.8.2 and 4.8.3).

However, the LAI did not reach such high levels in 1979 as in 1980. All three sowings reached a plateau LAI value of about 5, whilst in 1980 the June sowing attained a value of 7 in late September, and then decreased to under 5 by the final harvest. The July sowing reached a lower peak, but then decreased for only two weeks before levelling off at a similar final value. Thus all the treatments in both 1979 and 1980 reached a final LAI of a similar value.

The 1978 results, over the latter half of the season, showed LAI reaching even higher peak values than in 1980, of 7 - 9, which then declined to about 6 by the final harvest (Figure 4.8.1). In 1978 there were no significant differences between varieties from the June sowing, and there were only significant differences at the first two harvests of the July sowing. At the first harvest Lair had a significantly higher LAI than the other two varieties, whilst at the second Raphanobrassica had increased to a comparable value, but Maris Kestrel was still significantly lower. Over the same period leaf yields did not vary much, and there were no significant differences between varieties.

In 1979 Lair had a significantly higher LAI at three of the first four harvests from the first sowing and all of the first four harvests of the second sowings (Figure 4.8.2 and 4.8.3). This early superiority in LAI reflected that in total and leaf yield, but was even more marked. Lair also had a higher LAI throughout the season from the third sowing, but due to high variability there were no significant differences until the final harvest, when both Lair and Raphanobrassica were significantly higher than Maris Kestrel.

From both the first and second sowing there was a sudden halt in the increase of LAI of Lair at the beginning of September, which coincided with the date of the cessation of leaf growth. Raphanobrassica and Maris Kestrel continued to increase in LAI for a further four weeks, again as with leaf yield, and there were thus no significant differences in final LAI. From the third sowing Raphanobrassica stopped increasing in LAI at the beginning of October, but Lair and Maris Kestrel continued to increase, reaching a pronounced peak at the end of October, and then decreasing in LAI to the final harvest. This was in constrast to leaf yields, which showed a reduction in growth at the beginning of October.

From the first and third sowings Maris Kestrel had the lowest early LAI, but from the second it was Raphanobrassica, with its low population density, that had the lowest early LAI. Raphanobrassica did not reach comparable values to the other varieties until early October, which was two weeks later than the date by which it had compensated in leaf yield. The much higher leaf yields of the first sowing of Raphanobrassica during the latter half of the season were not reflected to such an extent in LAI, although Raphanobrassica did have a significantly higher LAI at the penultimate harvest.

Lair again had a superior LAI during the early part of the 1980 season, from both sowings (Figure 4.8.4). This was in spite of the similarity in leaf yields over this period. Maris Kestrel had the lowest, and Raphanobrassica intermediate values. There were significant differences between varieties at the first five harvests of the June sowing, and the first six of the July sowing. Both sowings produced a decline in LAI at the same time as their leaf yield stopped increasing. There were no significant differences in LAI between varieties once the decline in values had started.

As with the other parameters, the early development patterns of LAI of the two sowing dates were similar. The June sowing continued to increase in LAI for a longer period, but subsequently decreased so that final values of LAI were similar.

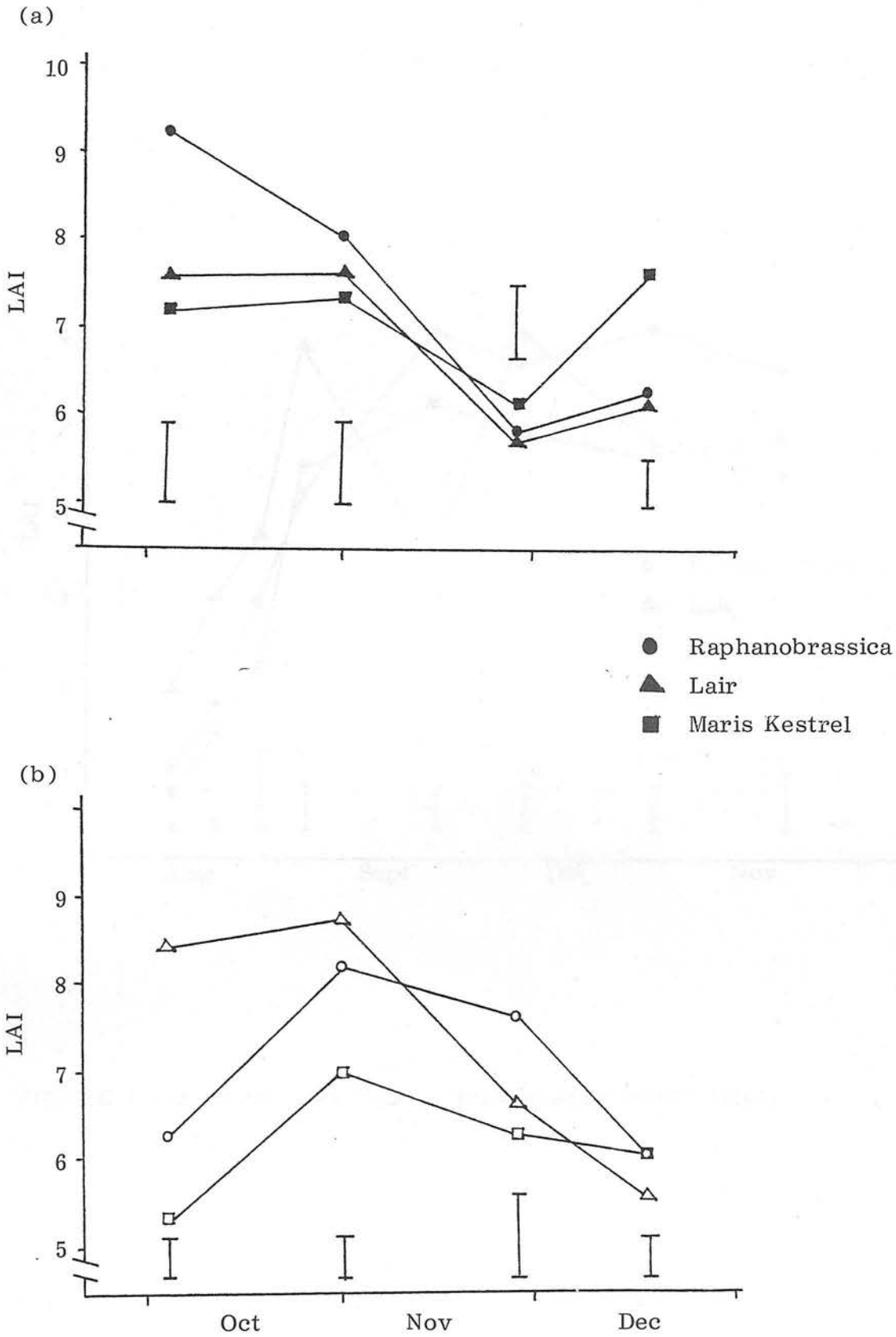


FIGURE 4.8.1: Leaf Area Index 1978. (a) June sowing;
(b) July sowing.

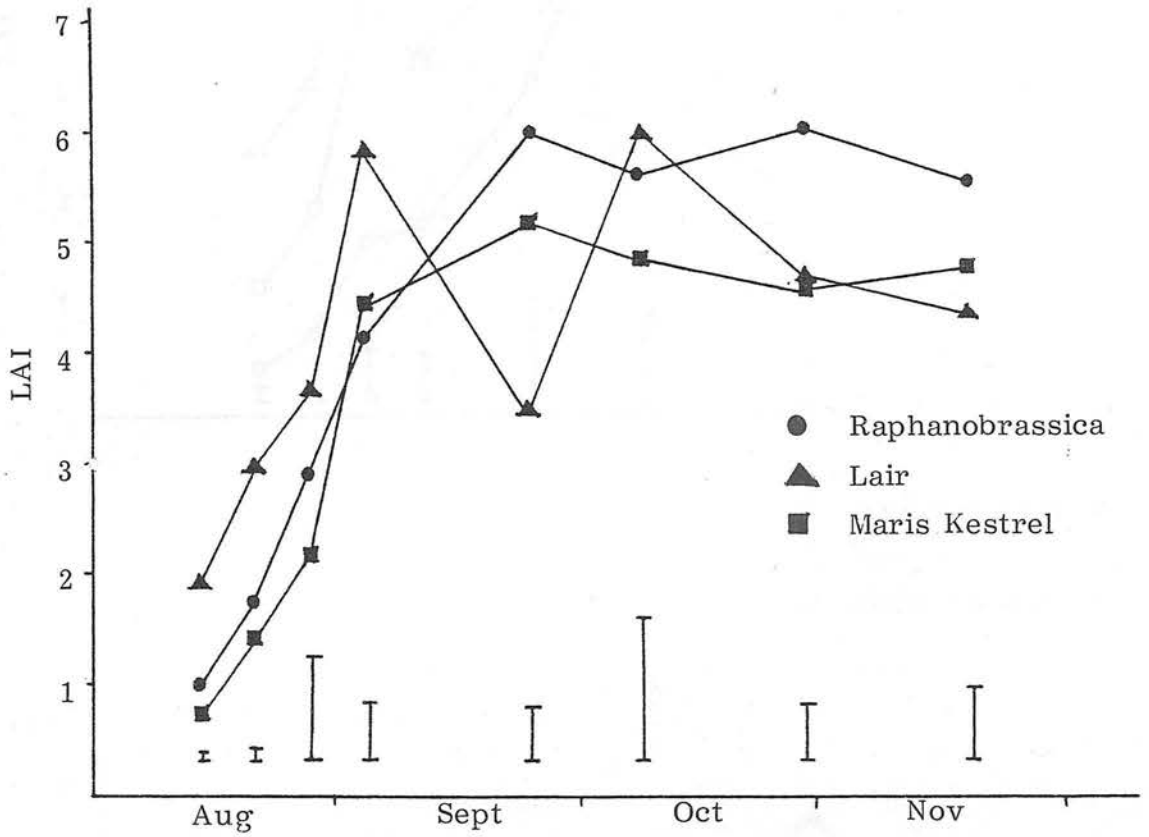


FIGURE 4.8.2: Leaf Area Index. First sowing (early July).

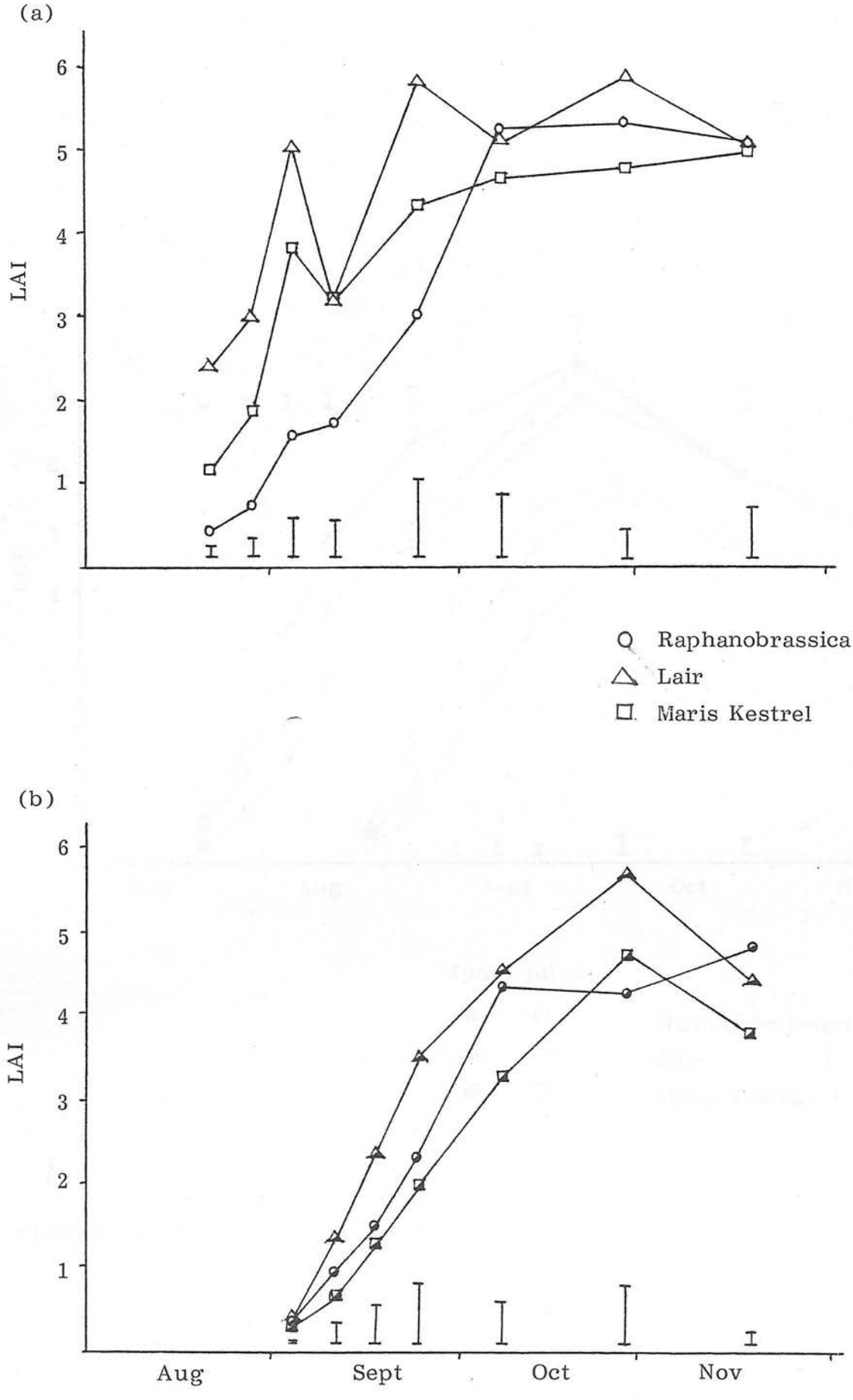


FIGURE 4.8.3: Leaf Area Index 1979. (a) second sowing (late July); (b) third sowing (early August).

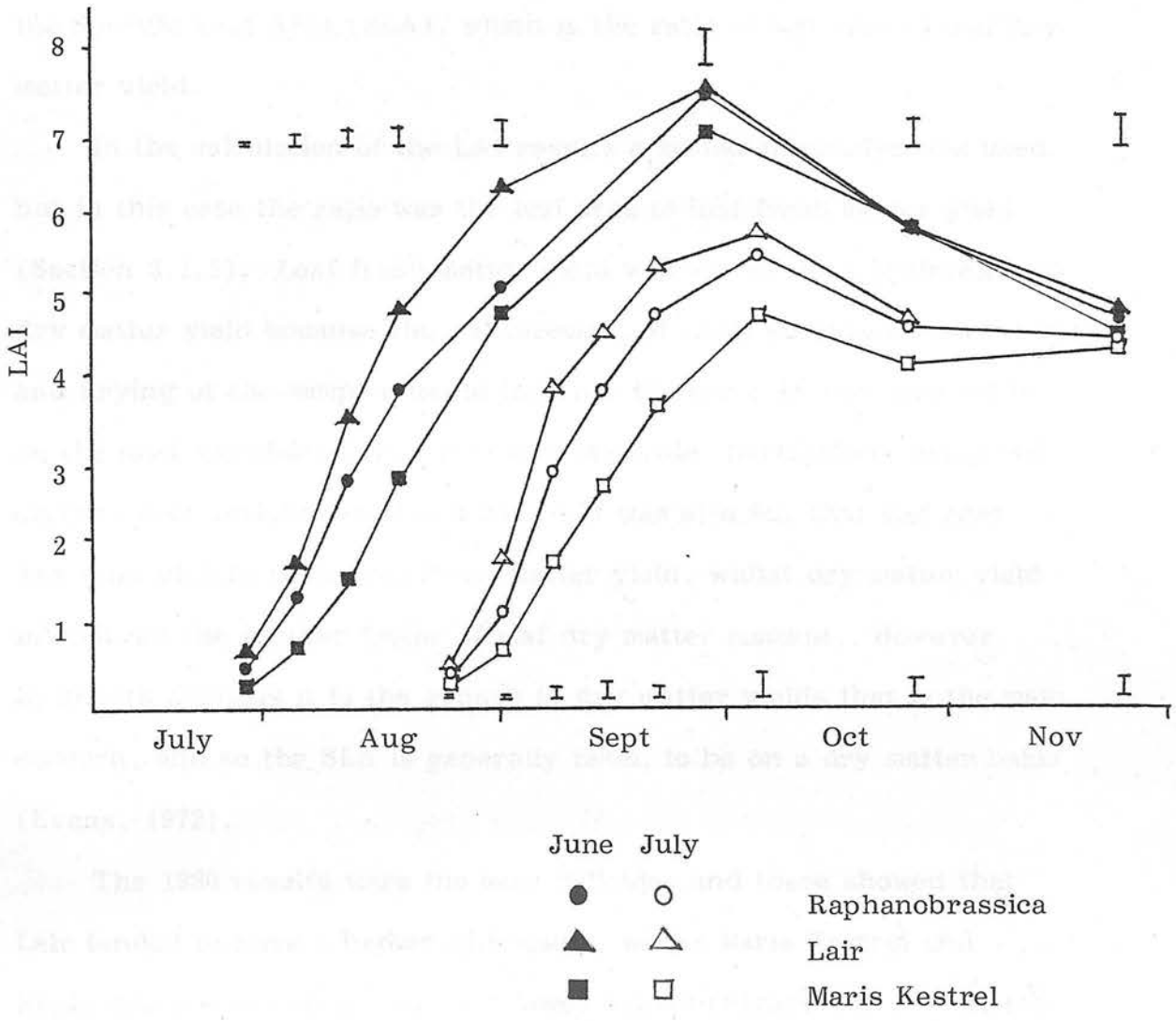


FIGURE 4.8.4: Leaf Area Index 1980.

4.9 Specific Leaf Area

Although there were some similarities between the leaf yield and LAI results, there were also certain differences, which indicated that the relationship between leaf dry matter yield and leaf area was changing, both in time and between varieties. A measure of this relationship is the Specific Leaf Area (SLA), which is the ratio of leaf area to leaf dry matter yield.

In the calculation of the LAI results a similar parameter was used, but in this case the ratio was the leaf area to leaf fresh matter yield (Section 3.1.5). Leaf fresh matter yield was employed in preference to dry matter yield because the measurement of small weights was necessary, and drying of the samples would increase the error in what proved to be the most variable of the measurements made, particularly using the earlier, disc method (Section 3.5). It was also felt that leaf area was more closely related to fresh matter yield, whilst dry matter yield introduced the further factor of leaf dry matter content. However, in growth analysis it is the growth in dry matter yields that is the main concern, and so the SLA is generally taken to be on a dry matter basis (Evans, 1972).

The 1980 results were the most reliable, and these showed that Lair tended to have a higher SLA value, whilst Maris Kestrel and Raphanobrassica had similar, but lower values (Figure 4.9.1). At the beginning of the season the SLA was increasing, less markedly from the June sowing, when the increase was only over the first three harvests, but more markedly from the July sowing, when the increase was sustained over five harvests. However, from both sowings it was the more rapid increase in SLA of Lair over this period that established its superior value for the rest of the season.

Lair had a significantly higher SLA than the other two varieties at all but the first and last harvests from the June sowing and at all but the first harvest from the July sowing. These higher SLA values of Lair accounted for its higher LAI than Raphanobrassica, whilst having a similar or lower leaf yield.

The July sowing had lower initial SLA values than the June sowing, and thus in spite of its longer period of increase reached a similar maximum value, of about 30 $m^2\ kg^{-1}$ for Raphanobrassica and Maris Kestrel, and 35 $m^2\ kg^{-1}$ for Lair. Having reached a maximum, values immediately declined from the July sowing, but from the June sowing a short period of decrease was followed by a brief recovery before the onset of a general decline. From both sowings, the period of general decline coincided with a similar decline in LAI (Figure 4.8.4), whilst leaf yield was remaining constant (Figure 4.3.4). Thus both differences in LAI through the season, and between varieties, were due more to differences in SLA, rather than to differences in leaf yield.

The results for 1978 and 1979 were too variable to show anything but general trends. There was a reduction in SLA as the season advanced, evidence of an increase in SLA early in the season, as in 1980, but all three sowings in 1979 started the season with values similar to the maximum noted in 1980. At the few harvests where significant differences occurred, it was always Lair that had the superior value, confirming the trend noted from the 1980 results.

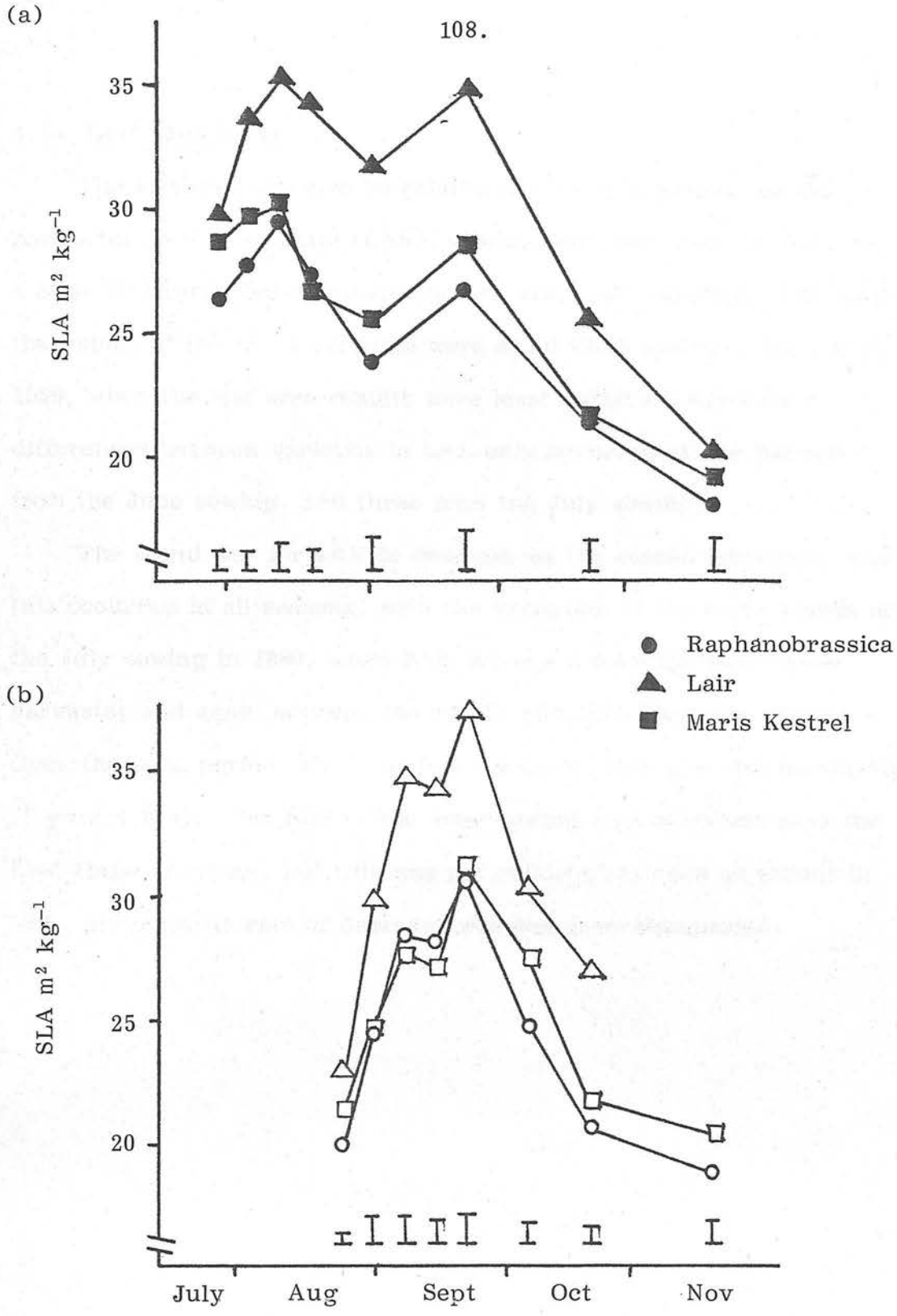


FIGURE 4.9.1: Specific Leaf Area 1980. a) June sowing; b) July sowing.

4.10 Leaf Area Ratio

The leaf area can also be related to total dry weight, as the parameter Leaf Area Ratio (LAR). Unlike with SLA, where there was a clear difference between Lair and the other two varieites, with LAR the values of the three varieties were at all times similar. Even in 1980, when the leaf area results were least variable, significant differences between varieties in LAR only occurred at one harvest from the June sowing, and three from the July sowing.

The trend was for LAR to decrease as the season advanced, and this occurred in all seasons, with the exception of the early season of the July sowing in 1980, when LAR increased over the first three harvests, and again between the fourth and fifth harvests (Figure 4.10.1). Over the same period, the first five harvests, SLA was also increasing (Figure 4.9.1). The SLA of the June sowing also increased over the first three harvests, but this was not reflected to such an extent in LAR, although its rate of decrease was less over this period.

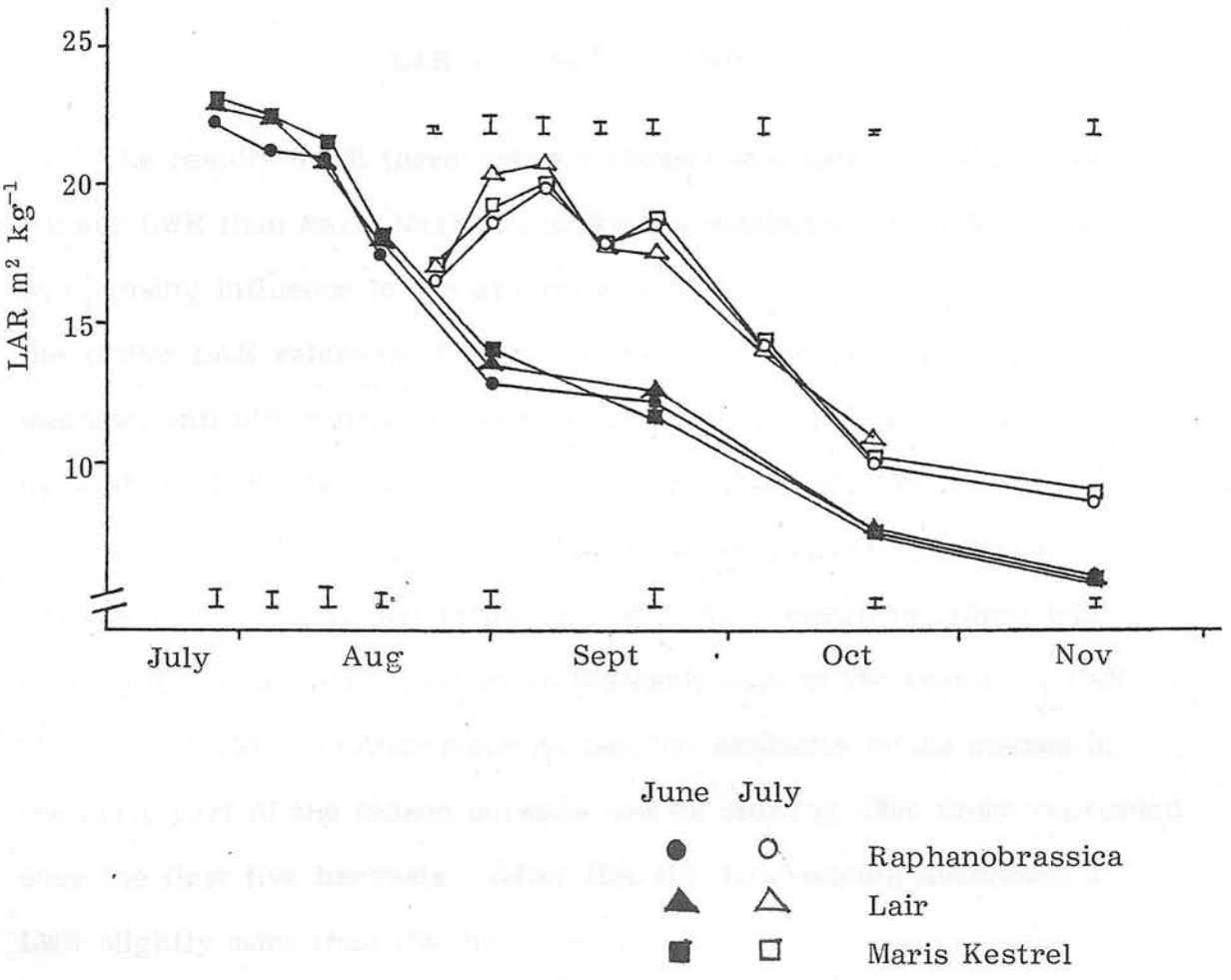


FIGURE 4.10.1: Leaf Area Ratio 1980.

4.11 Leaf Weight Ratio

The Leaf Weight Ratio (LWR) is the ratio between leaf and total dry matter yield, and can thus be regarded as a measure of the "leafiness" of a crop. It is of particular interest as the factor linking SLA and LAR, in the relationship:

$$LAR = SLA \times LWR$$

The results in all three seasons showed that Lair tended to have a lower LWR than Maris Kestrel and Raphanobrassica. This acted as an opposing influence to the greater SLA of Lair, and thus produced the similar LAR values of the three varieties. The variability of LWR was low, and differences between varieties were significant at all harvests in 1980, and at all but one in both 1978 and 1979.

As with SLA and LAR, LWR tended to decrease as the season advanced, but in contrast to the previous two parameters, there was no divergence from this pattern in the early part of the season in 1980 (Figure 4.11.3). Another contrast was the similarity of the curves in the early part of the season between sowing dates in 1980 which continued over the first five harvests. After this the June sowing decreased in LWR slightly more than the July sowing.

The LWR curves in 1978 and 1979 (Figures 4.11.1 and 4.11.2) were also similar in form. In all three seasons the LWR values tended to reduce from a maximum of approximately 0.8 to a minimum of approximately 0.4.

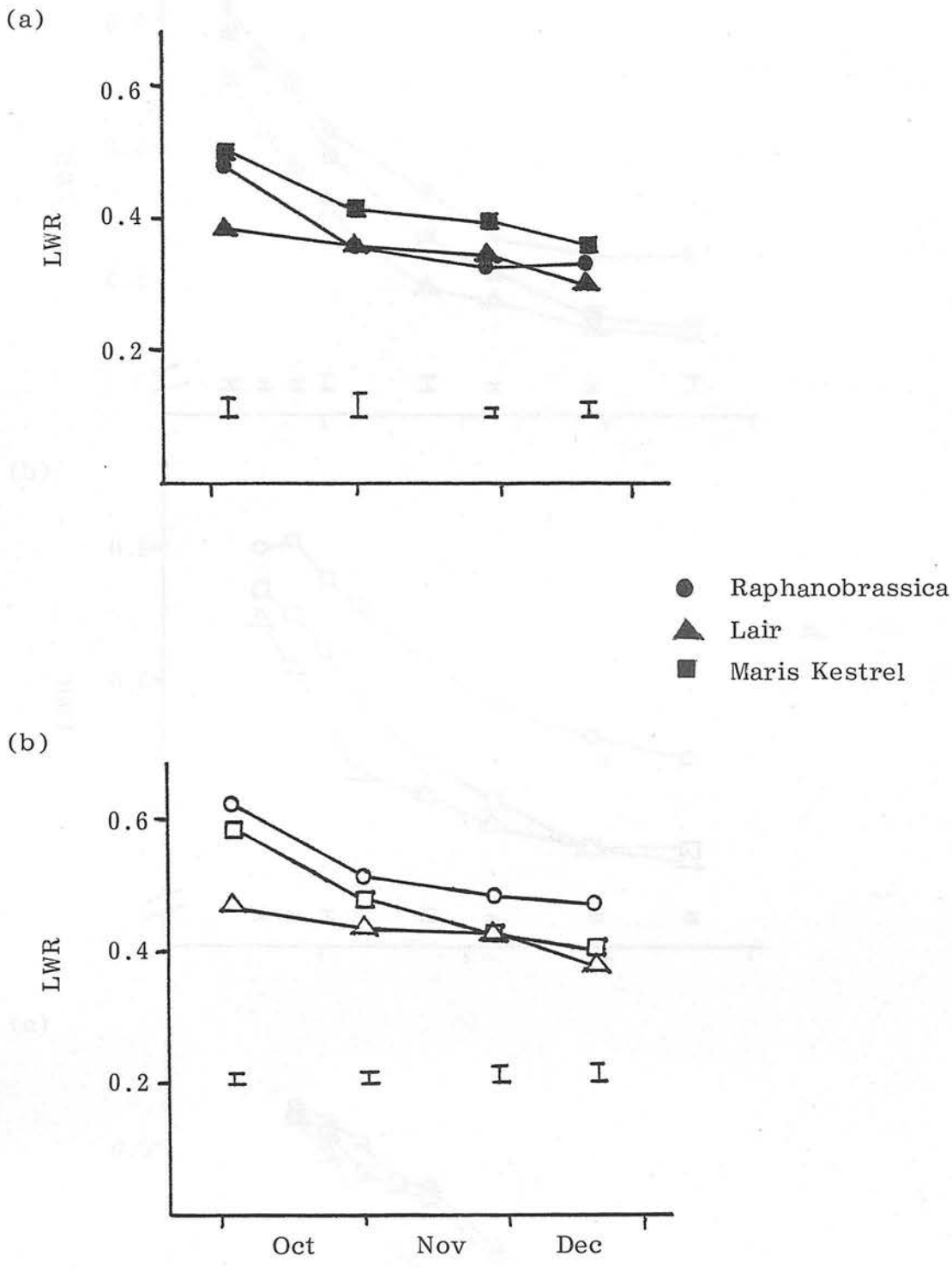


FIGURE 4.11.1: Leaf Weight Ratio 1978. (a) June sowing; (b) July sowing.

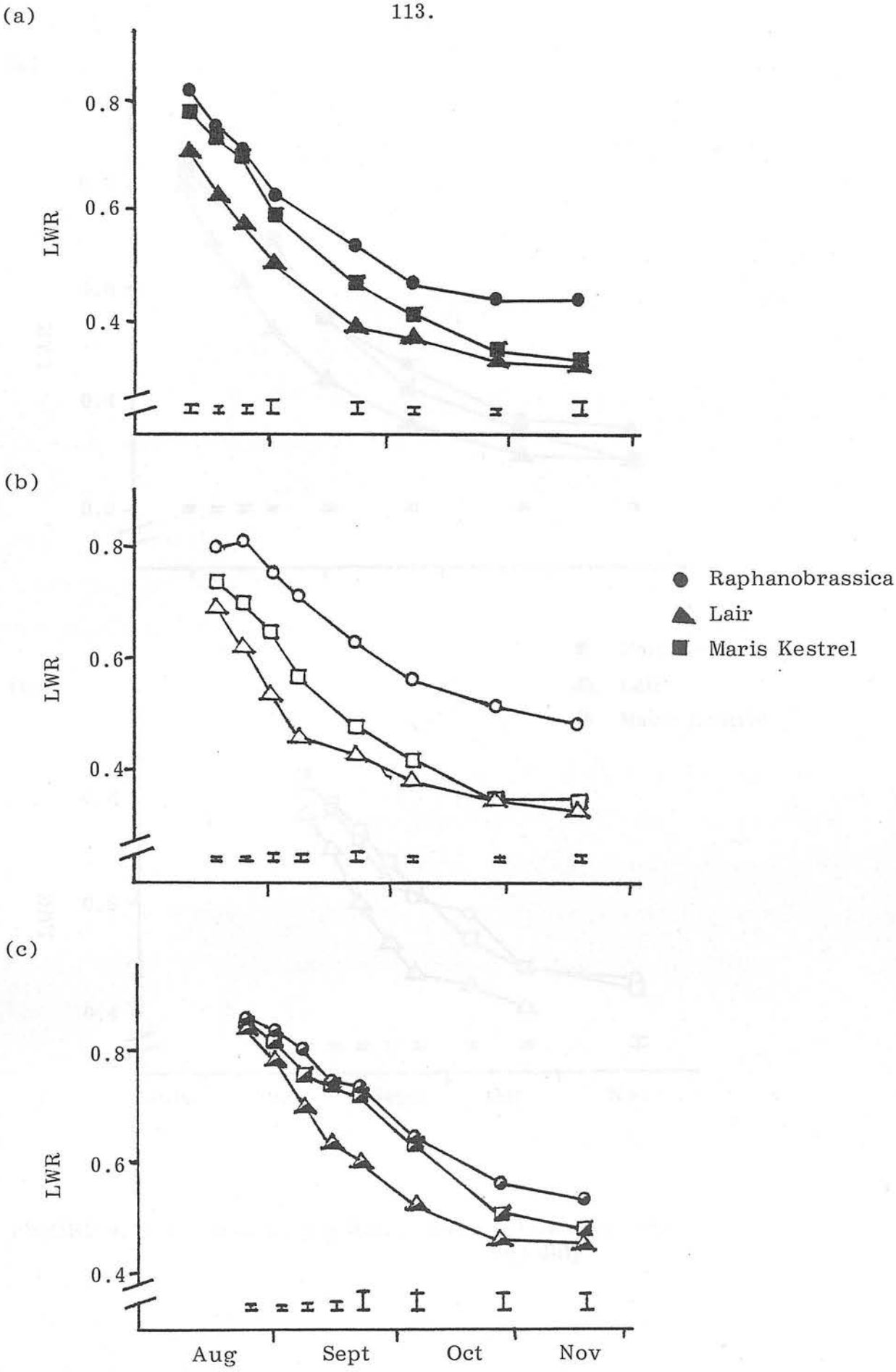


FIGURE 4.11.2: Leaf Weight Ratio. (a) first sowing (early July); (b) second sowing (late July); (c) third sowing (early August).

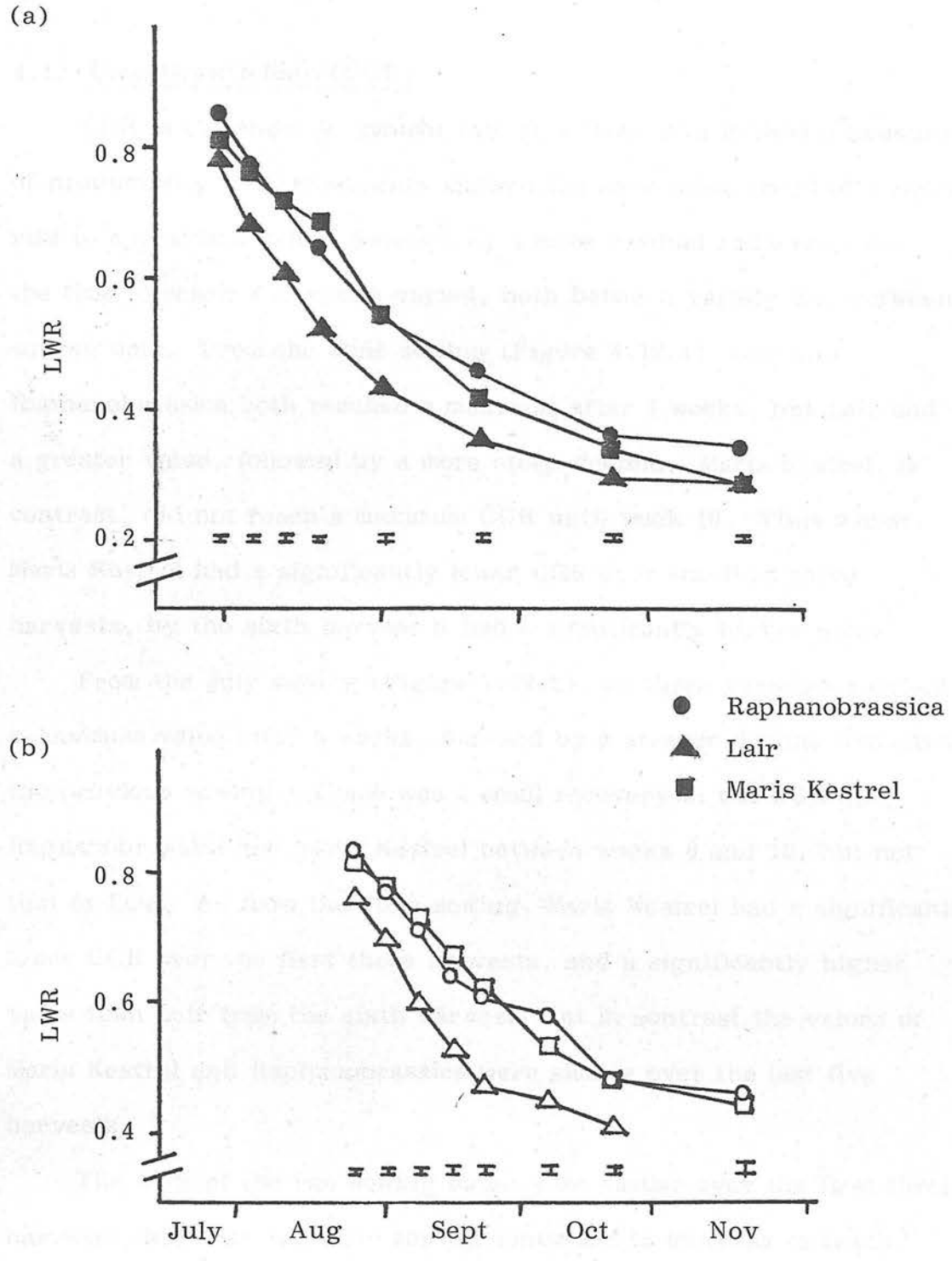


FIGURE 4.11.3: Leaf Weight Ratio 1980. (a) June sowing; (b) July sowing.

4.12 Crop Growth Rate (CGR)

CGR is the absolute growth rate of a crop, and is thus a measure of productivity. All treatments showed the same basic trend of a rapid rise to a maximum value, followed by a more gradual reduction, but the time to reach a maximum varied, both between variety and between sowing date. From the June sowing (Figure 4.12.1), Lair and Raphanobrassica both reached a maximum after 7 weeks, but Lair had a greater value, followed by a more steep decline. Maris Kestrel, in contrast, did not reach a maximum CGR until week 10. Thus whilst Maris Kestrel had a significantly lower CGR over the first three harvests, by the sixth harvest it had a significantly higher value.

From the July sowing (Figure 4.12.2), all three varieties reached a maximum value after 6 weeks, followed by a steeper decline than from the previous sowing. There was a small recovery in the CGR of Raphanobrassica and Maris Kestrel between weeks 8 and 10, but not that of Lair. As from the June sowing, Maris Kestrel had a significantly lower CGR over the first three harvests, and a significantly higher value than Lair from the sixth harvest, but in contrast the values of Maris Kestrel and Raphanobrassica were similar over the last five harvests.

The CGR of the two sowing dates were similar over the first three harvests, but then the June sowing continued to increase to reach a later, and higher maximum value, and sustained this advantage until the end of the season.

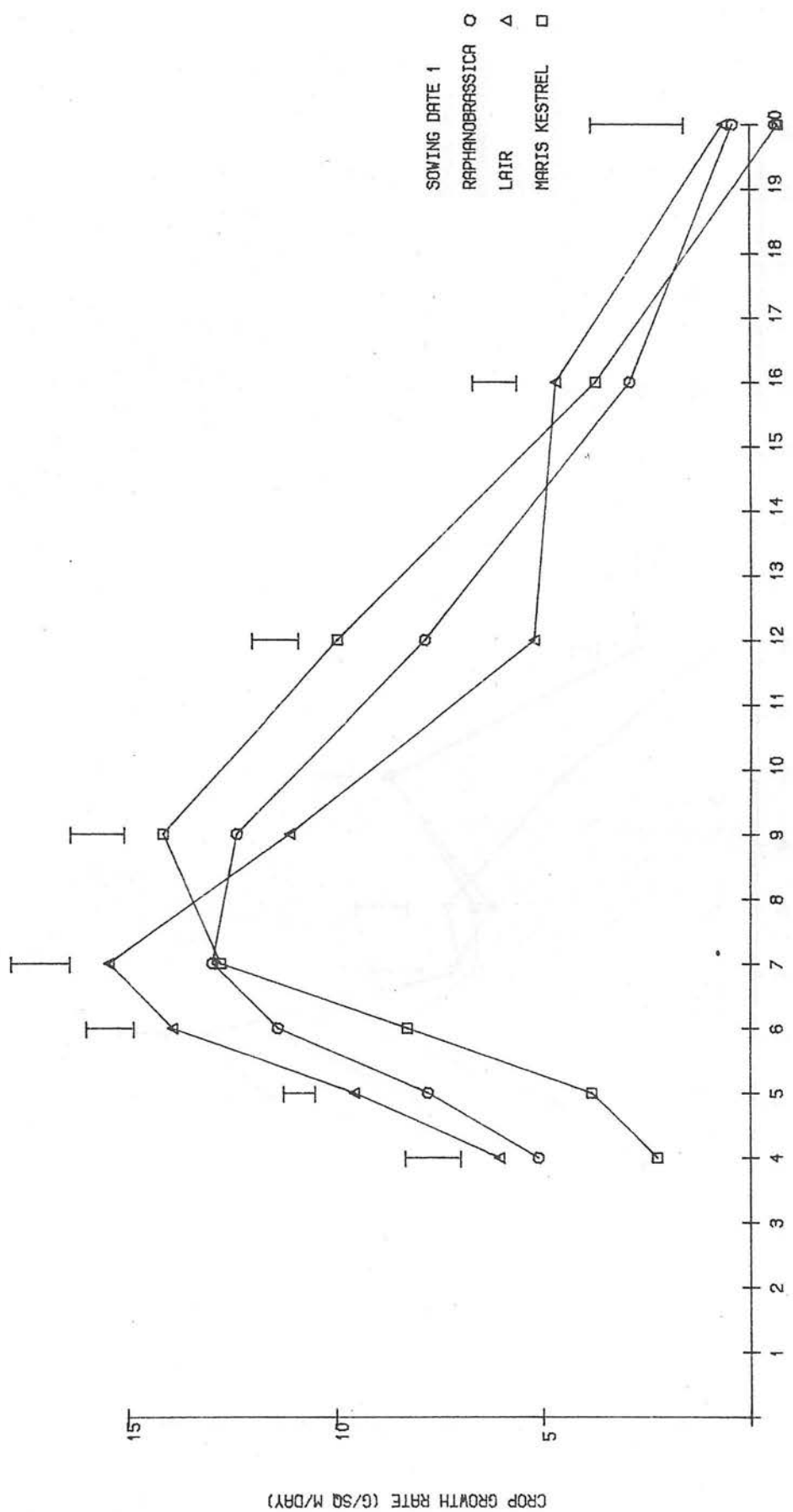


FIGURE 4.12.1: Crop Growth Rate, 1980 experiment, June sowing.

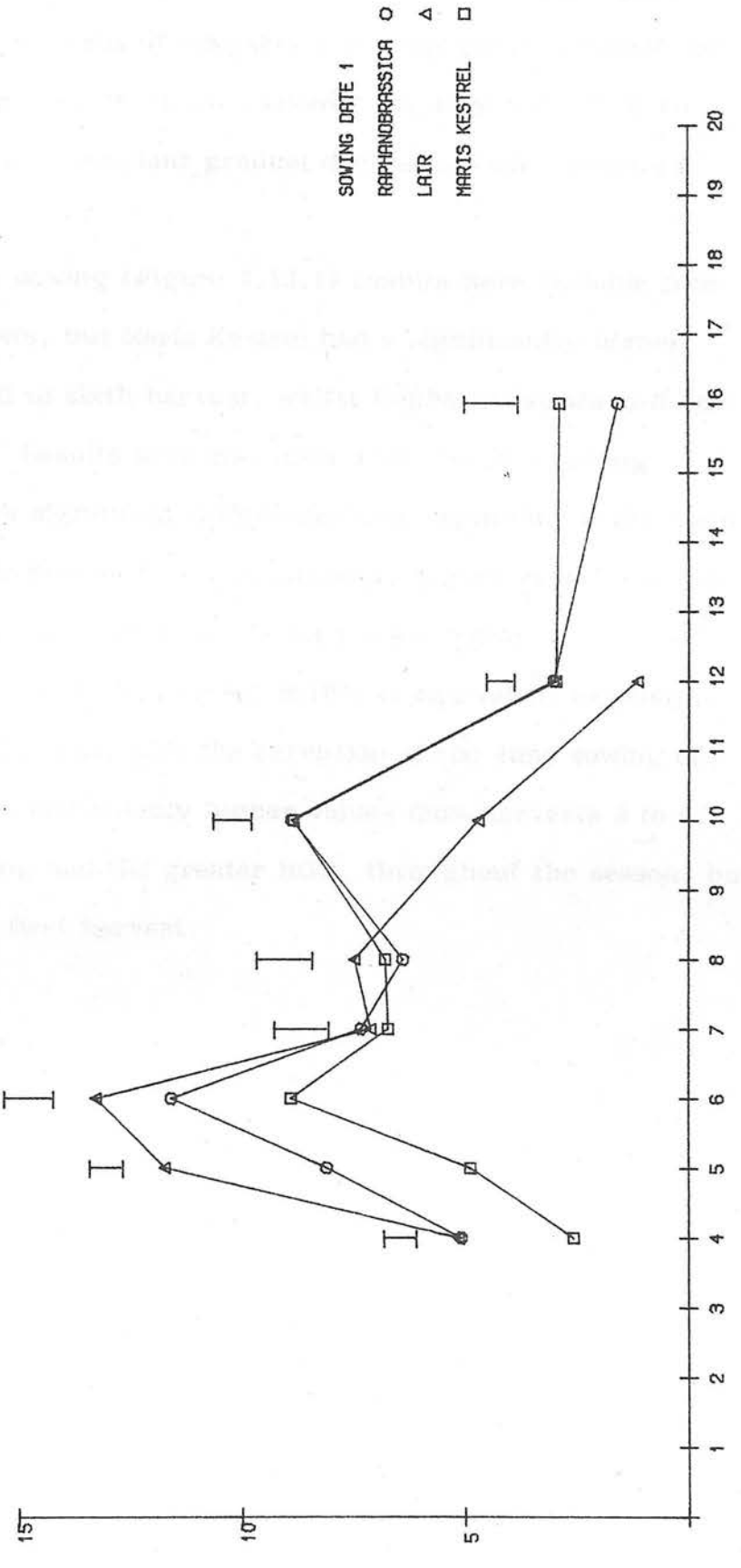


FIGURE 4.12.2: Crop Growth Rate, 1980 experiment, July sowing.

4.13 Relative Growth Rate (RGR)

RGR is the growth rate of a crop in relation to its actual yield, and thus it is a better basis of comparison of crop growth, though not of crop productivity. All treatments showed the same pattern of an initially steep, but a subsequent gradual decline in RGR, towards a zero value.

From the June sowing (Figure 4.13.1) results were variable from the first two harvests, but Maris Kestrel had a significantly higher value from the third to sixth harvest, whilst Raphanobrassica and Lair had similar values. Results were less clear from the July sowing (Figure 4.13.2) with significant differences only occurring at the third harvest, when Maris Kestrel had a significantly higher value, and the sixth harvest, when Lair had a significantly lower value.

The two sowing dates had similar RGR's at equivalent harvests, at all but the first harvest, with the exception of the June sowing of Maris Kestrel, which had notably higher values from harvests 3 to 6.

The June sowing had the greater RGR, throughout the season, but most notably at the first harvest.

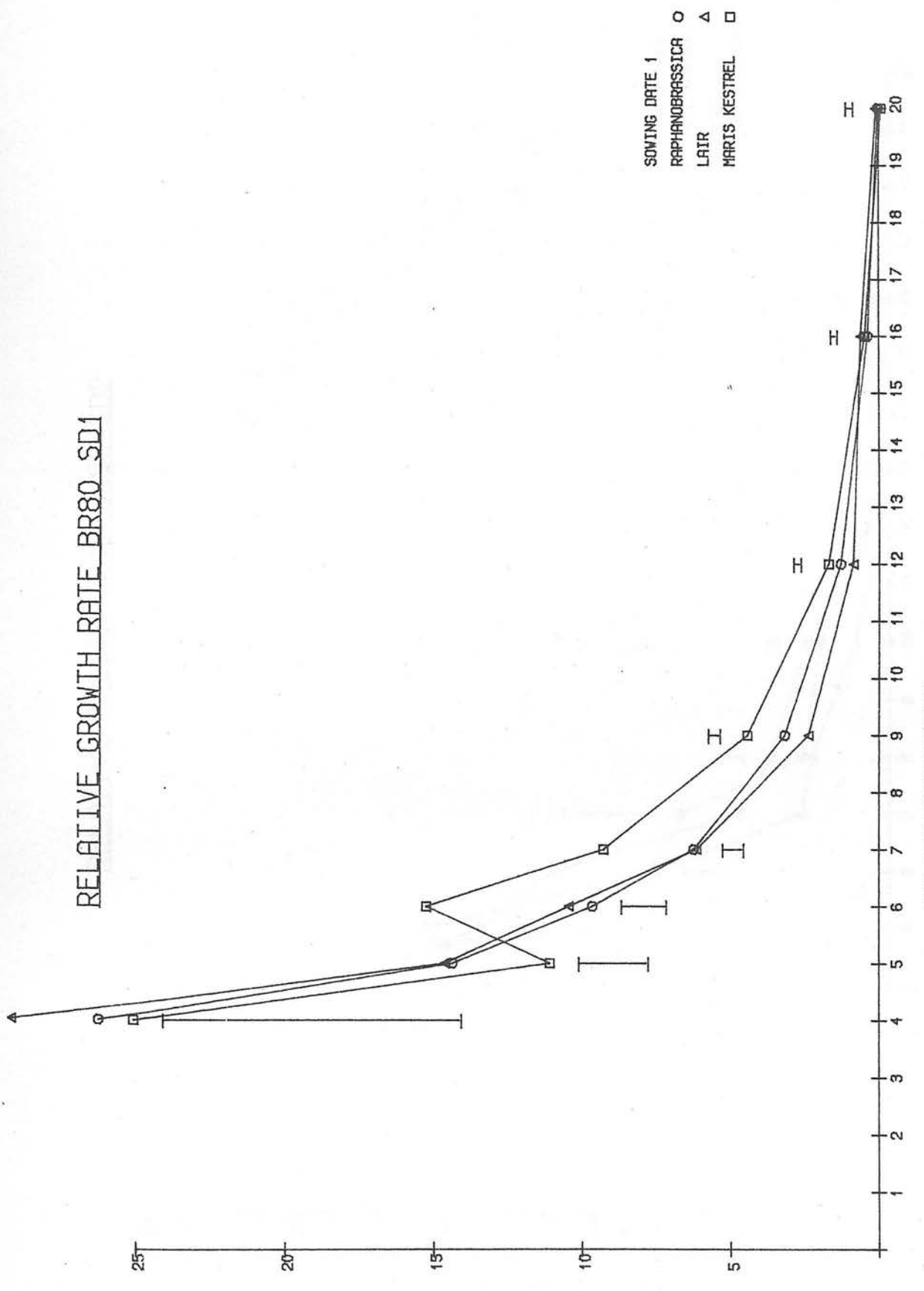


FIGURE 4.13.1: Relative Growth Rate, 1980 experiment, June sowing.

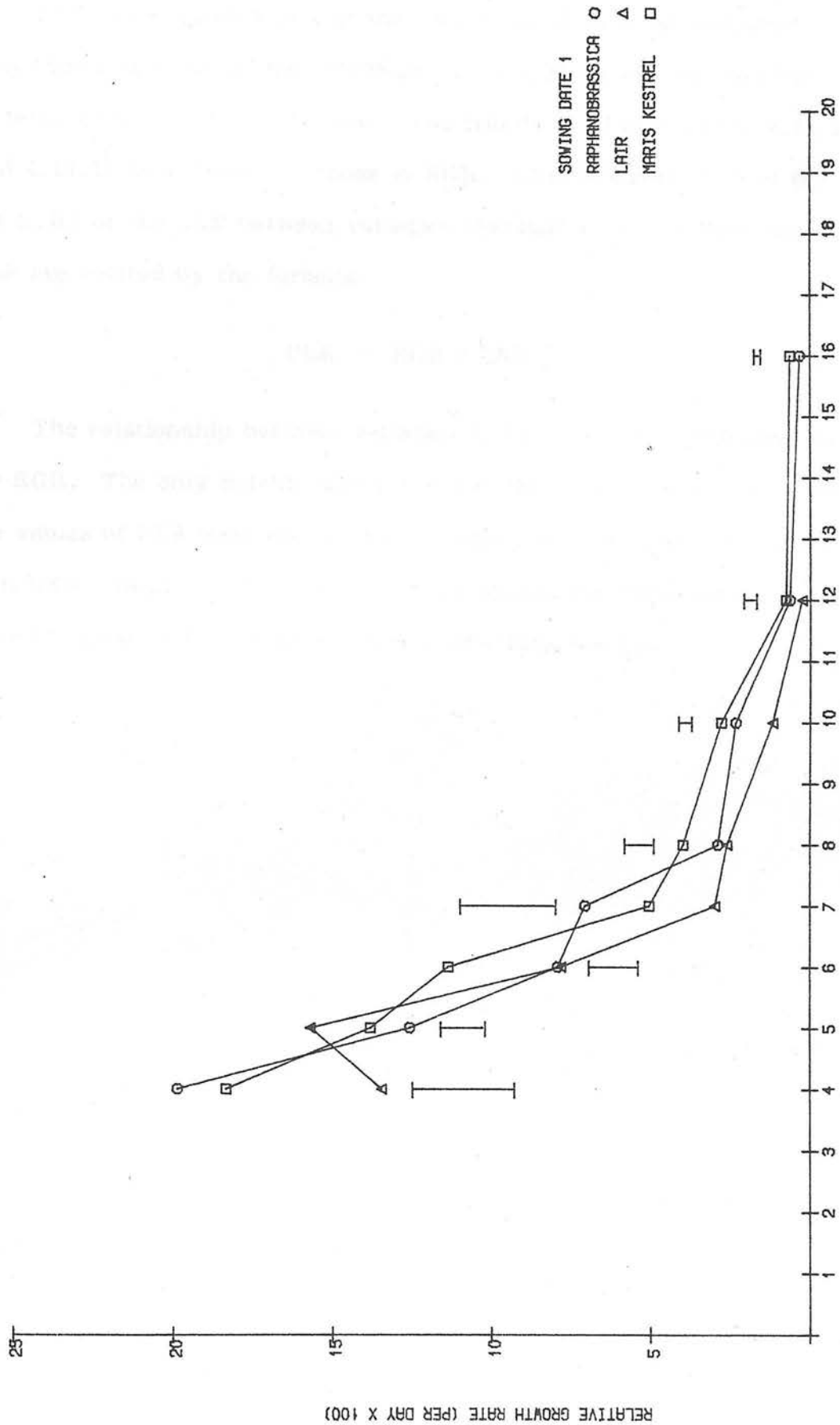


FIGURE 4.13.2: Relative Growth Rate, 1980 experiment, July sowing.

4.14 Unit Leaf Rate (ULR)

ULR is the growth rate of the crop in relation to its leaf area. It is thus a measure of the efficiency of the leaf surface of the plant in terms of assimilate production. The trends in ULR (Figures 4.14.1 and 4.14.2) were similar to those in RGR. This is a reflection of the similarity of the LAR between varieties (Section 4.10), as RGR and ULR are related by the formula:

$$ULR = RGR / LAR$$

The relationship between varieties in ULR were thus the same as for RGR. The only notable difference was that at the first two harvests the values of ULR were not notably greater from the June sowing, as with RGR. However, for the rest of the season the June sowing did have the greater ULR in comparison to the July sowing.

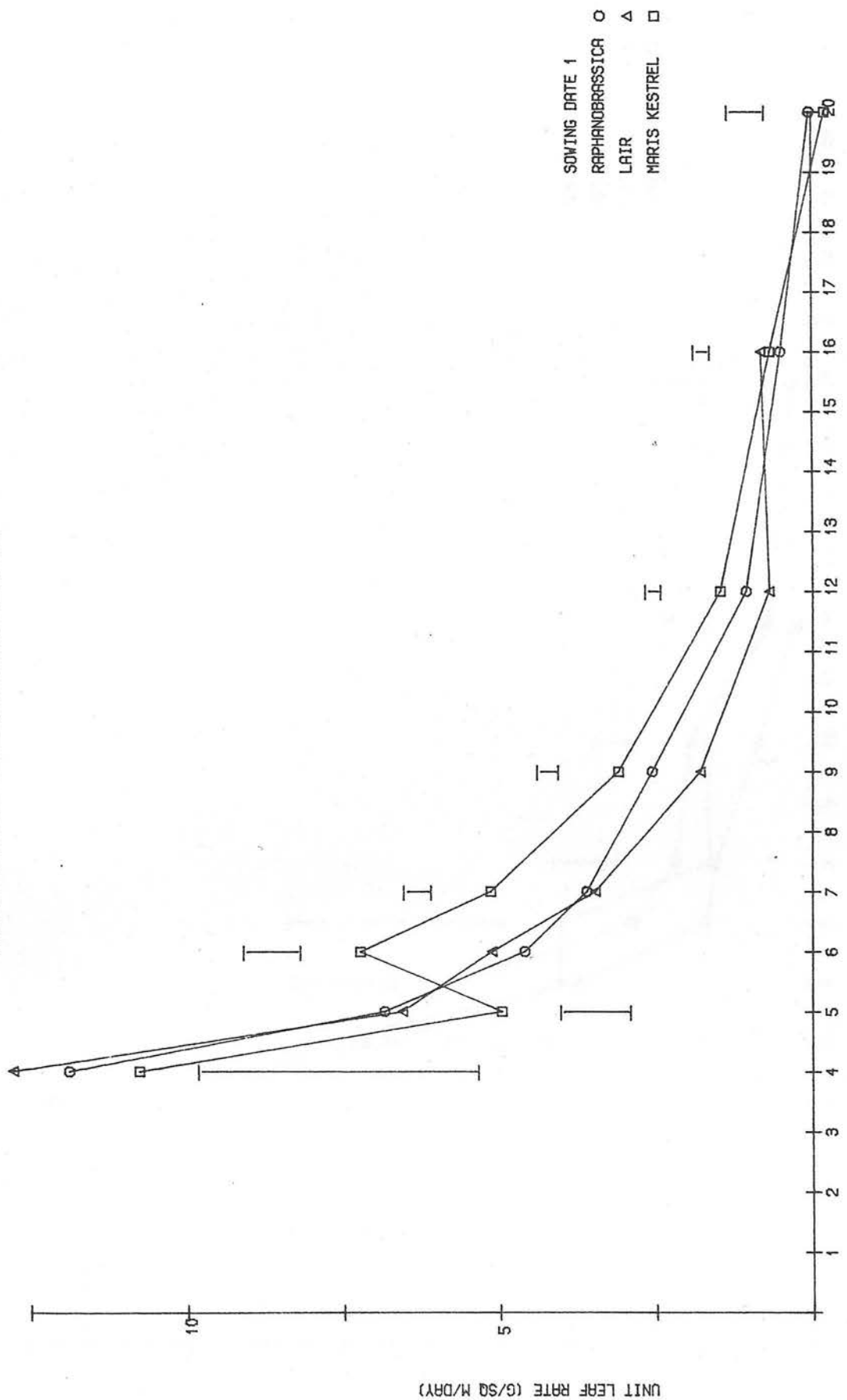


FIGURE 4.14.1: Unit Leaf Rate, 1980 experiment, June sowing.

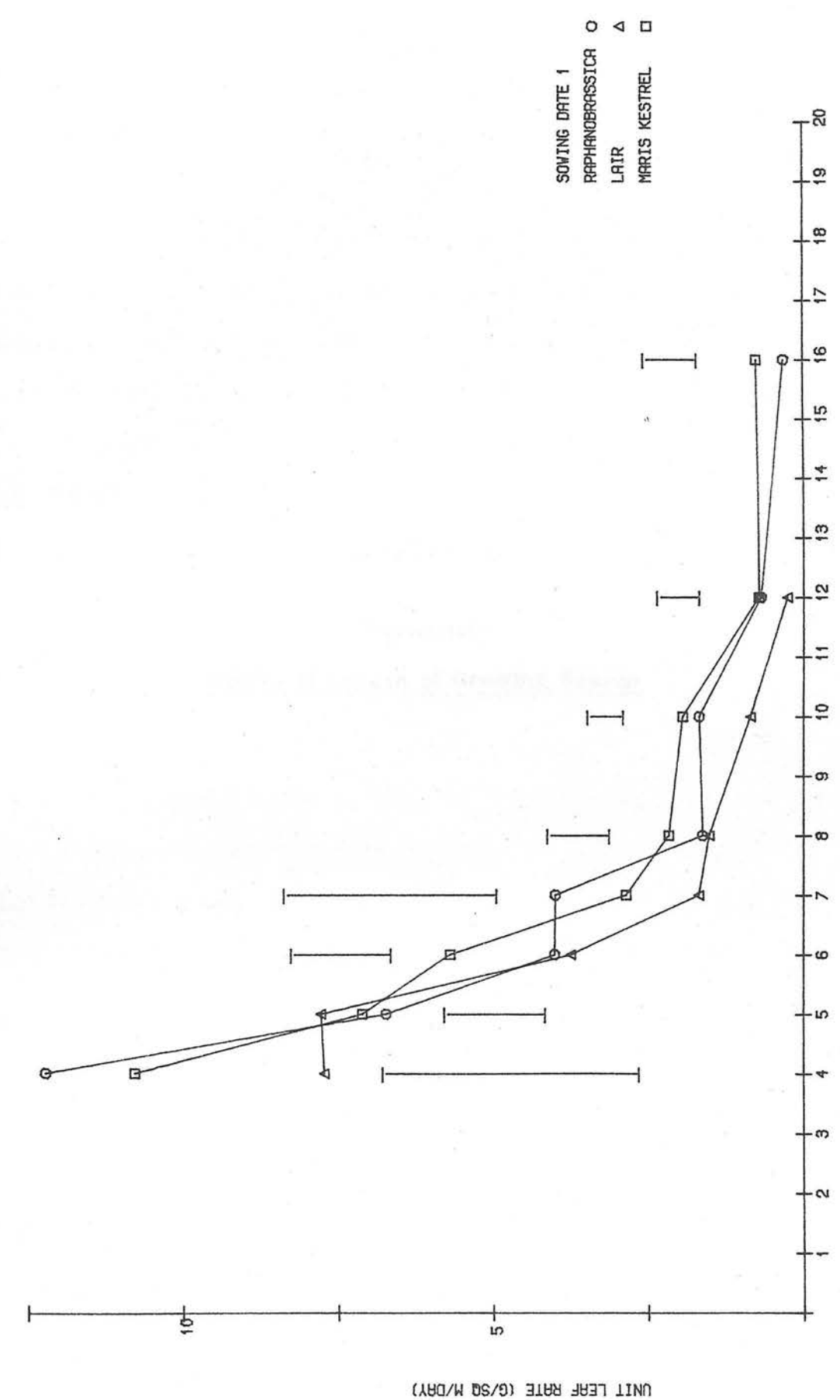


FIGURE 4.14.2: Unit Leaf Rate, 1980 experiment, July sowing.

CHAPTER V

Discussion:

Effects of Length of Growing Season

5.1 Length of Growing Season

Final total yields were found to be linearly related to the length of growing season (Figure 4.2.5). This response was linked to the environmental resources available over the period of growth. There was a variation in the amount of radiation available for interception by the leaf canopy of the crop between seasons, there being 15% less in 1980 compared to 1979 (Appendix III). It was found that if final total yields were regressed against available radiation after emergence, a similar linear relation to that against length of growing season was obtained, with a slightly greater overall correlation ($r = 0.91$). There was again no difference in the regressions of the three varieties.

Mean air temperatures were less variable between seasons. The most notable difference was the warmer autumn temperatures in 1978, particularly in November, but this did not have any great effect on overall growth. Rainfall was more variable, but again showed little effect on overall growth, apart from the delay in emergence of the first sowing due to dry conditions in July 1979 (Table 3.6.2).

Few previous experiments have included a range of sowing dates so as to establish a clear relationship between length of growing season and yield. It was generally found that yield increased with increasing

length of growing season (Section 2.3.1). From a series of trials over several seasons at the Grassland Research Institute a linear relationship between length of growing season and yield of radish was found (Sheldrick *et al*, 1981). The regression had a much lower slope than that found in these results, and similar experiments with rape failed to show any significant relationship.

Splitting the plant into its various components illustrated how these components were contributing to the overall yield pattern. From the range in final leaf, petiole and stem yields it is clear that it was the stem fraction that was the main contributor to the differences in total yield. The leaf and petiole final yields both covered a comparatively small range, regardless of season or sowing date. Whilst the sowing date mean values of final total yield ranged from 3.82 - 9.02 t ha^{-1}, over the three seasons, those of leaf and petiole ranged from 3.08 - 4.60 t ha^{-1}, and stem yield ranged from 0.74 - 4.42 t ha^{-1}. The bulk of the variation was thus in stem yield, which suggests that there was a control or limitation on the maximum leaf and petiole yield. The general shape of their growth curves also suggest this. A maximum asymptotic value seemed to be reached, which was then maintained, or slightly declined from, for the rest of the season (Figures 4.3.2 - 4.3.5 and 4.4.2 - 4.4.5). Other experiments have not considered these components of yield, and it is thus impossible to determine if this relative stability in final leaf and petiole yield is general.

Stem yields continued to increase steadily until the end of the season. There was thus a period during the latter half of the season when the yield of stem was increasing whilst that of leaf and petiole was static or decreasing. However, it is possible that leaf and petiole

production also continued at a steady rate, but that later in the season leaf senescence increased to balance the rate of production.

The LAI results provide some support for this hypothesis. Considering the less variable 1980 results the final values were within a remarkably small range (Figure 4.8.4) and even including the results of the previous seasons the range was not great. This lack of variability in final LAI values between sowing dates was even more marked than that in leaf and petiole yields. This implicates LAI as the dominant limiting factor, with leaf and petiole growth being linked to the production of a certain LAI value. Theoretical considerations support such a model, by suggesting that there is an optimum LAI value for maximum growth. Above this value mutual shading reduces the light available to lower leaves to such an extent that their photosynthetic rate is exceeded by their respiration, causing a net loss of assimilates. Such a relationship between LAI and CGR has been demonstrated in kale (Watson, 1956; Watson and French, 1962). The magnitude of the optimum LAI value also depends on light and temperature conditions, as examplified by studies on clover (Black, 1963).

Thus the sharp peaks in the LAI results for 1980 (Figure 4.8.4) could be explained as being due to the production of a supra-optimal LAI, which caused the lower leaves to become unproductive and senesce, thus reducing the LAI. The difference in peak LAI values between sowing dates, and the continued reduction until the end of the season were then due to the declining levels of incident radiation, and lower temperatures, as the season advanced (Appendix III), which reduced the optimum LAI values.

This pattern of leaf growth and senescence also explains the changing relationship between leaf area and leaf yield, as measured by

SLA. The increase in leaf area proceeded at a faster rate than the increase in leaf yield early in the season. This occurred particularly from the July sowing, and there was thus a marked increase in SLA (Figure 4.9.1). Similarly, the decrease in LAI at the end of the season was not reflected in leaf yield, which remained at a constant level, and there was a decrease in SLA at this time.

The pattern in SLA can be explained if it is assumed that older, fully expanded leaves had a higher SLA. It follows that during the period of early growth, when all leaves were retained, the proportion of older leaves, and thus the overall SLA, increased. Conversely, during the later part of the season the older leaves senesced and were lost, causing the decrease in SLA.

The similarity in final leaf yields and petiole yields and the general linear relationship between overall yield and length of growing season suggest that differences in environment between seasons and sowing date were not having any great effect on the general growth pattern of the crop. However, the more detailed analysis of growth possible from the 1980 experiment, due to the extensive nature of the trial and the more reliable measurement of leaf area, did provide an indication of certain sowing date effects.

At the first harvests, when both were of an equivalent age, the July sowing had a lower SLA, but this increased at a greater rate than that of the June sowing. By the fourth harvest the SLA of the two sowings were similar (Figure 4.9.1). The later-sown crop thus had fewer expanded leaves at the four week stage, and the expansion occurred at a greater rate to compensate over the following four weeks.

The LWR values, however, were similar for the two sowings early in the season, and in consequence the LAR values were lower for the

July sowing. In fact the July sowing had a rising trend in LAR over the first three harvests, which was in contrast to the usual seasonal drift (Figure 4.10.1). The LAI values over this period were similar, and the lower LAR of the July sowing was due to a greater total weight.

Another parameter to show differences in early trends between sowing dates was DMC. The July sowing had a greater initial DMC, which rapidly decreased over the first five harvests, in contrast to the June sowing, which maintained a constant DMC over this period (Figure 4.7.3). The net effect of this was to produce similar fresh weights between the sowing dates at equivalent ages. Thus at the four week post-emergence stage, when sampling began, the June sowing had a lower dry weight yield than the July sowing, but through a greater SLA and DMC had a similar LAI and fresh weight yield. The radiation received by the two sowings over the four week period from emergence was similar, but temperatures were some 2-3°C higher during August than in July (Appendix III), which could account for the greater yield of the July sowing. However, leaf area development was not affected, and occurred at the same rate from both sowings, thus producing the lower SLA and LAR in the July sowing.

Over the following four weeks of development, i.e. the period from four to eight weeks post-emergence, these differences in the morphology of the two sowings disappeared. The June sowing had a greater RGR (Figure 4.13.1), and thus compensated for its initially lower dry weight yield. At the same time the development of leaf area in both sowings proceeded at the same rate, as did that of fresh weight yield. The result was that the SLA of the July sowing increased, and the DMC decreased, to reach a similar level to that of the June

sowing. In fact by the eight week stage all the parameters of the two sowings were broadly similar.

In contrast to the first four weeks of development, mean temperatures were similar for the two sowings over the second four weeks, but radiation was 35% lower for the July sowing. Thus the greater RGR of the June sowing over this period was related to a greater level of radiation.

From the eight week stage onwards the total yield production of the July sowing became less than that of the June sowing. This was mostly due to the differences in stem growth rate that became established at this stage (Figure 4.5.5). Similar leaf growth rates were maintained until maximum values were reached (Figure 4.3.5), and as a result the LWR of the July sowing became greater than that of the June sowing. However, this was balanced by a greater reduction in SLA due to earlier senescence of lower leaves, which led to a continuing similarity in the LAR of the two sowings.

The June sowing continued to have a superior RGR and, due to the similarity in LAR, also a superior ULR, over this period (Figures 4.13.1 and 4.14.1). If, however, these values are compared at the same harvest dates the July sowing is shown to have been much more efficient, in that it had a greater RGR and ULR. On the other hand, due to the smaller size of the crop, the CGR results show that the actual productivity of the two sowings at any one harvest was similar (Figure 4.12.1).

5.2 Varieties

The total growth curves of the three crops were basically similar, and resulted in final yields that were not significantly different, but contained within this overall pattern there were certain differences. These can be considered as two basic strategies, represented by Lair and Maris Kestrel, with Raphanobrassica following an intermediate course. Whilst Lair produced the superior early yields, Maris Kestrel sustained growth for a longer period, providing a comparable final yield, assuming the growing season was long enough. This early yield of advantage of rape is evidenced by its more favourable comparison, in variety trials, at later sowing dates, and hence a shorter growing season (ESCA, 1978; McNaughton and Ross, 1978; NOSCA, 1979; Harper and Compton, 1980).

To establish the basis for such differences in overall growth pattern it is necessary to examine the varietal variations in the various parameters of crop growth. In contrast to total yields, varietal differences occurred in final values of the components of yield. With the exception of the June sowing in 1978, Raphanobrassica always had the greatest final leaf yield, and apart from the August sowing in 1979 Lair had the lowest. The same pattern was followed by petiole yield, and the deficiencies for the production of equivalent final total yields were made up by stem yield. Raphanobrassica thus had the lowest final stem yields, again with the exception of the June sowing in 1978. The reason for the difference in response of Raphanobrassica from this sowing was its high level of flowering (Table 4.1.1). This caused stem elongation, and thus a greater production of stem, at the expense of leaf and petiole. Flowering also occurred from the June sowing in

1980, but at a lower level than in 1978 (Table 4.1.2). It thus only had the effect of reducing the varietal differences.

The differences in the components of final yield were not established early in the season, but developed as the season advanced. Initially Lair had the greatest leaf yield in 1979 (Figures 4.3.2 and 4.3.3), though Raphanobrassica had a similar leaf yield in 1980 (Figure 4.3.4). Such a seasonal variation was also apparent in petiole and stem yield, though to a lesser extent. Lair had the greatest initial petiole yields, in both seasons, but more notably in 1979 than 1980. Similarly the differences in Raphanobrassica and Maris Kestrel stem yields were greater in 1979.

These seasonal differences were probably due to the more closely controlled population densities in 1980 rather than any environmental changes. In 1979 differences in establishment led to inter-varietal population variations. In particular, Raphanobrassica had a low population from the second sowing (Table 6.2.2), whilst in 1980 the singling of plants to specific population densities led to little difference in variety mean populations (Table 6.2.4). This resulted in lower initial leaf and petiole yields in Raphanobrassica from the second sowing in 1979, although the crop later compensated to produce superior final yields. However, stem yield remained depressed throughout the season, producing a lower total yield.

The capacity of Raphanobrassica for sustained high levels of leaf and petiole growth was also notably evident from the first sowing in 1979, when at its peak level it produced 40-50% more leaf and 60% more petiole than the other two varieties (Figures 4.3.2 and 4.4.2). However, only a small advantage in final total yield was evident as a result of the

low stem yield. Raphanobrassica showed similar leaf and petiole growth patterns in 1980. In this season the leaf and petiole yields of Raphanobrassica were matched by those of Lair and Maris Kestrel, from the June sowing, though less so from the July sowing, particularly by Maris Kestrel petiole. There were similarly less varietal differences in stem yield in 1980.

A feature of the leaf growth of Lair was its abrupt cessation after an initial period of fast growth. This was notable from the first two sowings in 1979, when it occurred at an earlier date than the more gradual reduction in the rate of growth of the other crops, giving Lair the lowest leaf yield for the rest of the season (Figures 4.3.2 and 4.3.3). In 1980 the change occurred at a later date, and Lair had a lower leaf yield over the last two harvests only (Figure 4.3.4). Petiole growth, although having the same general trends, did not show such an abrupt change in Liar, and consequently yield differences were less pronounced late in the season (Figure 4.4.2 - 4.4.4).

The LAI results for 1979, although variable, did indicate that there was a sudden cessation in the increase in leaf area of Lair, corresponding to that in leaf yield (Figures 4.8.2 and 4.8.3). This did not lead to as a great a difference between varieties during the later part of the season as occurred with leaf yield. This was more clearly shown by the 1980 results (Figure 4.8.4). The reason for this was varietal differences in SLA, which were marked (Figure 4.9.1). Lair produced an equivalent LAI late in the season, in spite of a lower leaf yield, by virtue of a greater SLA. This also allowed it to produce a greater LAI early in the season in 1980, whilst having a similar leaf yield to Raphanobrassica (Figure 4.3.5).

If the leaf DMC of Lair and Raphanobrassica were similar, or that of Lair was the greater, then it can be concluded that the leaf thickness of Lair was less. Inspection of the data showed that this was the case. Leaf DMC followed the same pattern as DMC of the total plant, although with slightly greater values (Figure 3.7.3). Thus from the June sowing Lair had a greater leaf DMC from the fifth harvest onward and from the July sowing a similar value from the fifth harvest onward.

However, the similarity of the LAR values of the varieties showed that their leaf area was always in the same proportion to their leaf weight, i.e. the early superiority of Lair in LAI was by virtue of its greater yield over that period. The LWR of Lair was lower than that of the other two varieties (Figure 4.11.3), but this, was compensated by its greater SLA. This produced a similar LAR, due to the relationship:

$$LAR = SLA \times LWR$$

Thus Lair had less of its total yield in leaf, but through more efficient use of this yield maintained an equivalent leaf area to the other varieties.

Lair had the highest CGR, and Maris Kestrel the lowest, over the first four harvests from the June sowing, and the first three from the July sowing (Figure 4.12.1). The RGR values were not significantly different over the first two harvests. Maris Kestrel had the highest values over harvests 3-6 from the June sowing, though only at harvest 3 from the

July sowing (Figure 4.13.1). Thus, as with leaf area, the superior early CGR values of Lair were due to its greater yield at the time. The differences in early yield must, therefore, have been established in the four week period between emergence and the first harvest. Initial values of SLA, LWR and LAR seem to indicate this was the period of least morphological variation between varieties, and yet it produced the critical differences in yield that persisted in effect for at least two months.

A similar effect was found in a comparison of rape and radish (Johnston 1963). It was noted that the yield advantage of radish was established from a greater fresh weight growth rate over the first five weeks of growth. This is the only reported measurement of the early growth rate of these crops.

There is a parallel here with the sowing date effects where the first four weeks of growth showed differences in development between sowings. However, these differences were compensated for over the next four weeks. The Varietal differences, although not affecting final total yields, had a more lasting effect. They were also an influence on the differences in the partitioning of yield, which persisted until the end of the season.

CHAPTER VI

Results

Plant Population Density Effects

6.1 Introduction

The field experiments in 1978 and 1979 were designed to examine sowing date effects alone, but due to differences in emergence percentages and plant survival variation in plant population density arose between treatments (Tables 6.2.1 and 6.2.2). It was thus important to establish the effects of variation in plant population density on yield, and its components, on the crops examined. An additional experiment was therefore established in 1979, and population density was included as one of the factors in the 1980 experiment.

The 1979 population experiment had four plant population densities, as the only treatment on the three crops (Section 3.6.3). The results shown are the means of the four replicates. The 1980 experiment also had four plant population density treatments, but also included two sowing dates to examine interactions between the two factors (Section 3.6.4). Results are presented for each variety and sowing date, at each population density, and are the means of the three replicates. There were eight harvests (Table 3.6.4) and in order to simplify presentation the results from only three are graphically presented. The harvests were selected to represent the early, mid and late season, and were 4 August, 1 September and 20 October from the June sowing and 1 September, 22 September and 20 October from the July sowing.

6.2 Plant Population Density

Plant population density differed from the other treatment factor, sowing date, in that it varied with time. The treatment was, in fact, only the initial plant population density, as established by singling, at the beginning of the season, and actual plant population density can be considered as another variable parameter.

The initial plant population densities in the 1979 population experiment ranged from 13 - 52 m^{-2}. The final populations, at the harvest in November, were slightly lower than the initial populations in the lower three treatments, but in the highest population treatment the plant numbers had declined substantially (Table 6.2.3). This effect was greater in Lair and Raphanobrassica than in Maris Kestrel, with the result that there was a significant difference between varieties in final populations, and also a significant interaction between variety and initial population.

This tendency for a greater reduction in plant numbers at a higher population was also shown in the 1980 experiment, and it was an effect that increased as the season advanced (Table 6.2.4). A greater range in initial population was used in this trial, 13 - 78 m^{-2}, and the self-thinning effect was even more marked at the higher population. However, interaction between variety and initial population was only significant at two harvests, the sixth harvest from both the June and July sowing. Nonetheless the lower population of Raphanobrassica at the highest initial population treatment gave it an overall final population significantly lower than Lair and Maris Kestrel at all but the first harvest from a June sowing, though at only one harvest from the July sowing.

Although significant differences between varieties occurred in both seasons, these differences were small in comparison to the initial population differences, and thus the distinction between population treatments was always maintained. The same was true of the general reduction in plant population as the season advanced.

Such reductions in population were also evident in the main field trials in 1978 and 1979, results of which are presented in Tables 6.2.1

and 6.2.2. This reduction occurred at a greater rate with increasingly higher initial populations. Thus Lair, from the second sowing in 1979, which had the highest initial population, 150 m^{-2}, had decreased to 90 m^{-2} by the end of the season.

The control over initial populations achieved by the singling was evident by the similarity of the variety means in 1980, an effect that persisted throughout the season. In contrast large differences between varieties occurred in the previous two seasons, due to variations in establishment when sowing to a stand. A test of field emergence in 1980 showed varietal differences, and also an interaction with sowing date (Appendix II).

In 1978, with the populations in the same range as the mean values in 1980, differences between varieties were significant throughout the season, from both sowings. Lair had the highest population and Raphanobrassica the lowest, with Maris Kestrel intermediate.

In 1979, higher populations were aimed for, with the consequence that correspondingly greater differences between varieties occurred. This was particularly evident from the second sowing, when Raphanobrassica was greatly affected by the dry conditions. In contrast to 1978, Maris Kestrel tended to have the highest population, rather than Lair.

Thus large differences in final population occurred between treatments in the 1978 and 1979 variety x sowing date experiments, due mostly to differences in initial establishment. Plant loss during the season had less effect and tended to reduce these differences. Initial populations were controlled by hand thinning in the 1979 population experiment and 1980 experiment. Nonetheless differences in final population developed between varieties, due to plant loss during the

season, but not to such an extent as in previous seasons, nor to such an extent as to confound initial population treatments.

TABLE 6.2.1: Plant population densities (m^{-2}), at each harvest, in the 1978 experiment. Calculated from plant counts at time of harvest.

Harvest date	June sowing:			July sowing:		
	RB	L	MK	RB	L	MK
5/9	21.5	34.2	24.4	25.4	47.1	37.7
3/10	21.8	33.0	24.7	24.1	40.0	35.9
31/10	21.2	30.9	25.5	27.0	46.0	36.6
28/11	23.2	32.8	26.9	29.4	47.1	38.1
19/12	22.3	31.4	26.6	27.1	46.5	37.5
mean	22.0	32.4	25.6	26.6	45.3	37.1

Treatment means: SED (within sowings) = 1.59
(between sowings) = 1.81

TABLE 6.2.2: Plant population densities (m^{-2}), at each harvest, in the 1979 field trial. Calculated from plant counts at each harvest.

Harvest date	Sowing 1:			Sowing 2:			Sowing 3:		
	RB	L	MK	RB	L	MK	RB	L	MK
13/8	94.9	113.0	134.4						
20/8	85.1	116.1	122.3	29.8	134.1	135.2			
27/8	98.8	121.9	124.2	33.9	147.6	151.1	71.4	79.7	103.4
3/9	88.6	119.9	133.1	33.7	146.6	148.7	77.6	92.5	120.3
10/9	-	-	-	35.9	152.6	144.4	78.9	94.8	110.5
18/9	-	-	-	-	-	-	75.1	91.7	110.8
24/9	78.9	105.5	127.8	39.7	139.5	146.9	72.0	96.9	110.8
8/10	77.4	99.7	122.9	30.5	113.7	141.5	87.9	85.6	106.7
29/10	74.5	76.9	100.4	30.7	89.4	115.1	66.3	76.9	96.4
19/11	73.7	85.9	108.3	31.9	99.9	135.6	69.2	99.7	107.3

TABLE 6.2.3: Plant population densities (m^{-2}), at harvest on 5 November, in the 1979 population experiment, at each target population density treatment.

Variety	Plant population (m^{-2}): 13	17	26	52	mean
RB	13.0	18.7	24.7	37.1	23.4
L	11.8	16.2	24.6	37.8	22.6
MK	12.8	17.0	25.1	46.4	25.3
mean	12.5	17.3	24.8	40.4	23.8

TABLE 6.2.4: Plant population densities (m^{-2}), at each target population treatment, and at each harvest, in the 1980 experiment.

JUNE SOWING							JULY SOWING						
Harvest date	Variety	Plant population (m^{-2}): 13	26	39	78	mean	Harvest date	Variety	Plant population (m^{-2}): 13	26	39	78	mean
28/7	RB	12.9	28.3	41.2	77.2	39.9	25/8	RB	12.9	24.9	37.1	73.1	37.0
	L	15.1	30.1	40.5	81.5	41.8		L	13.6	25.8	38.9	80.1	39.6
	MK	13.6	27.6	40.5	81.2	40.7		MK	12.7	24.2	35.8	74.2	36.7
	mean	13.9	28.7	40.7	80.0	40.8		mean	13.1	25.0	37.3	75.8	37.8
4/8	RB	13.8	24.6	36.0	78.1	38.1	1/9	RB	14.9	25.6	37.1	72.4	37.5
	L	14.3	28.3	36.2	78.7	39.4		L	10.9	25.5	35.5	77.6	37.4
	MK	13.4	26.7	40.7	72.4	38.4		MK	14.5	23.3	37.3	73.1	37.1
	mean	13.9	26.5	37.7	76.4	38.6		mean	13.4	24.8	36.6	74.4	37.3
11/8	RB	15.1	24.9	36.6	72.9	37.4	8/9	RB	13.4	24.7	36.4	68.6	35.8
	L	15.6	29.6	40.7	80.1	41.5		L	13.6	23.7	38.9	72.8	37.2
	MK	14.0	26.5	39.8	77.2	39.4		MK	12.7	22.4	35.0	68.8	34.7
	mean	14.9	27.0	39.0	76.8	39.4		mean	13.3	23.6	36.7	70.1	35.9
18/8	RB	13.1	24.2	34.6	68.3	35.0	16/9	RB	13.4	23.6	35.7	67.0	35.4
	L	14.5	27.1	37.6	84.6	41.0		L	12.9	25.1	36.2	78.5	38.2
	MK	15.1	28.9	38.7	74.0	39.2		MK	12.5	22.2	34.6	71.2	35.1
	mean	14.2	26.7	37.0	75.6	38.4		mean	13.0	24.3	35.5	72.2	36.3
1/9	RB	14.2	23.8	37.3	65.4	35.2	22/9	RB	12.7	23.8	33.0	65.2	33.7
	L	14.5	27.6	38.4	75.3	38.9		L	11.8	25.8	39.6	74.9	38.0
	MK	14.3	26.0	36.6	74.6	37.9		MK	12.2	23.7	35.7	71.3	35.7
	mean	14.3	25.8	37.4	71.7	37.3		mean	12.3	24.4	36.1	70.5	35.8
22/9	RB	14.0	24.4	30.5	54.7	30.9	6/10	RB	12.7	24.4	36.0	56.8	32.5
	L	15.4	22.4	35.0	65.8	34.6		L	12.5	25.8	37.3	75.8	37.8
	MK	14.9	24.4	35.5	69.5	36.1		MK	13.4	23.1	34.6	66.9	34.5
	mean	14.8	23.7	33.6	63.3	33.9		mean	12.9	24.4	36.0	66.4	34.9
20/10	RB	14.7	22.2	29.4	41.9	27.1	20/10	RB	12.7	24.0	32.8	55.0	31.1
	L	15.1	25.6	30.7	52.3	30.9		L	12.2	23.3	31.0	60.4	31.7
	MK	13.6	25.5	33.9	54.3	31.8		MK	13.8	23.1	33.0	59.5	32.4
	mean	14.5	24.4	31.3	49.5	29.9		mean	12.9	23.5	32.3	58.3	31.7
17/11	RB	14.2	21.3	29.6	47.1	28.1	17/11	RB	13.1	21.9	31.7	56.5	30.8
	L	14.0	26.2	33.9	51.4	31.4		L	10.2	24.9	35.7	50.9	30.4
	MK	15.1	23.1	30.3	53.4	30.5		MK	13.8	20.4	33.5	58.4	31.5
	mean	14.4	23.5	31.2	50.7	30.0		mean	12.4	22.4	33.6	55.3	30.9

6.3 Total Dry Matter Yield

The total dry matter yield increased with increasing population in both seasons, but the response was not great considering the wide range in populations. In the 1979 experiment the response was mostly in the range 13 - 26 pl.m^{-2} (Figure 6.3.1). At populations above 26 pl. m^{-2} the varieties varied in response. The yield of Raphanobrassica continued to increase, that of Maris Kestrel remained constant, and that of Lair decreased. However, such interactions between variety and population were not significant, although both population and variety differences were significant, as main effects.

The 1980 experiment showed that the response of total yield to population was proportionately greater early in the season, and reduced as the season advanced (Figures 6.3.2 and 6.3.3). From both sowing dates interaction between population and variety was significant at the first two harvests, but not thereafter. The tendency was for the response to population to be almost linear early in the season, and as the season progressed the response to population reduced, particularly at the higher populations. Thus the pattern at the late harvest was similar to that shown by the 1979 results. However, in 1979 the population response was confined mostly to the range 13 - 26 pl.m^{-2}, but in 1980 there was always some response in the range 13 - 39 pl.m^{-2}, until the end of the season.

The relationship between varieties was not changed appreciably by plant population, but there was a slight tendency for Lair to be affected less by population, particularly later in the season.

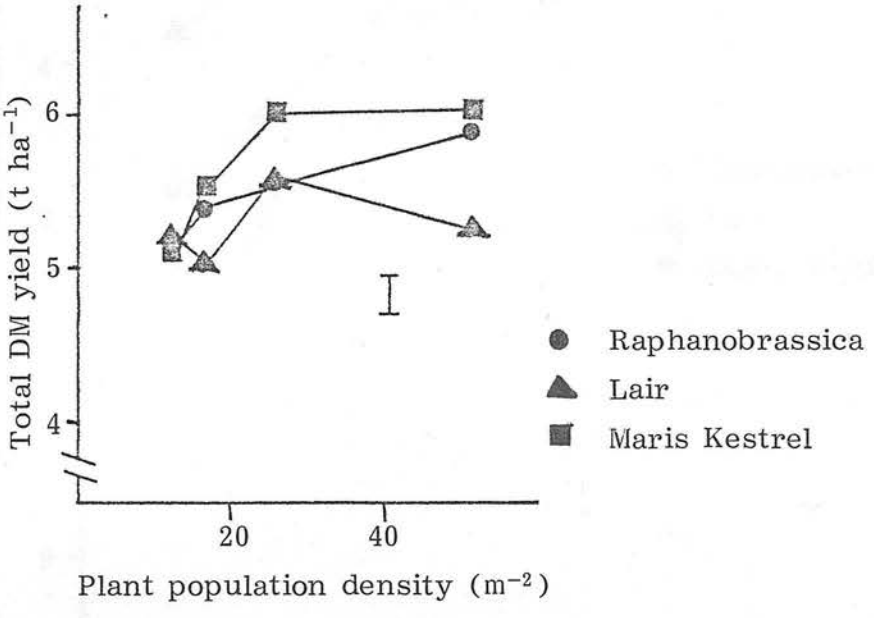


FIGURE 6.3.1: Total dry matter yield 1979.

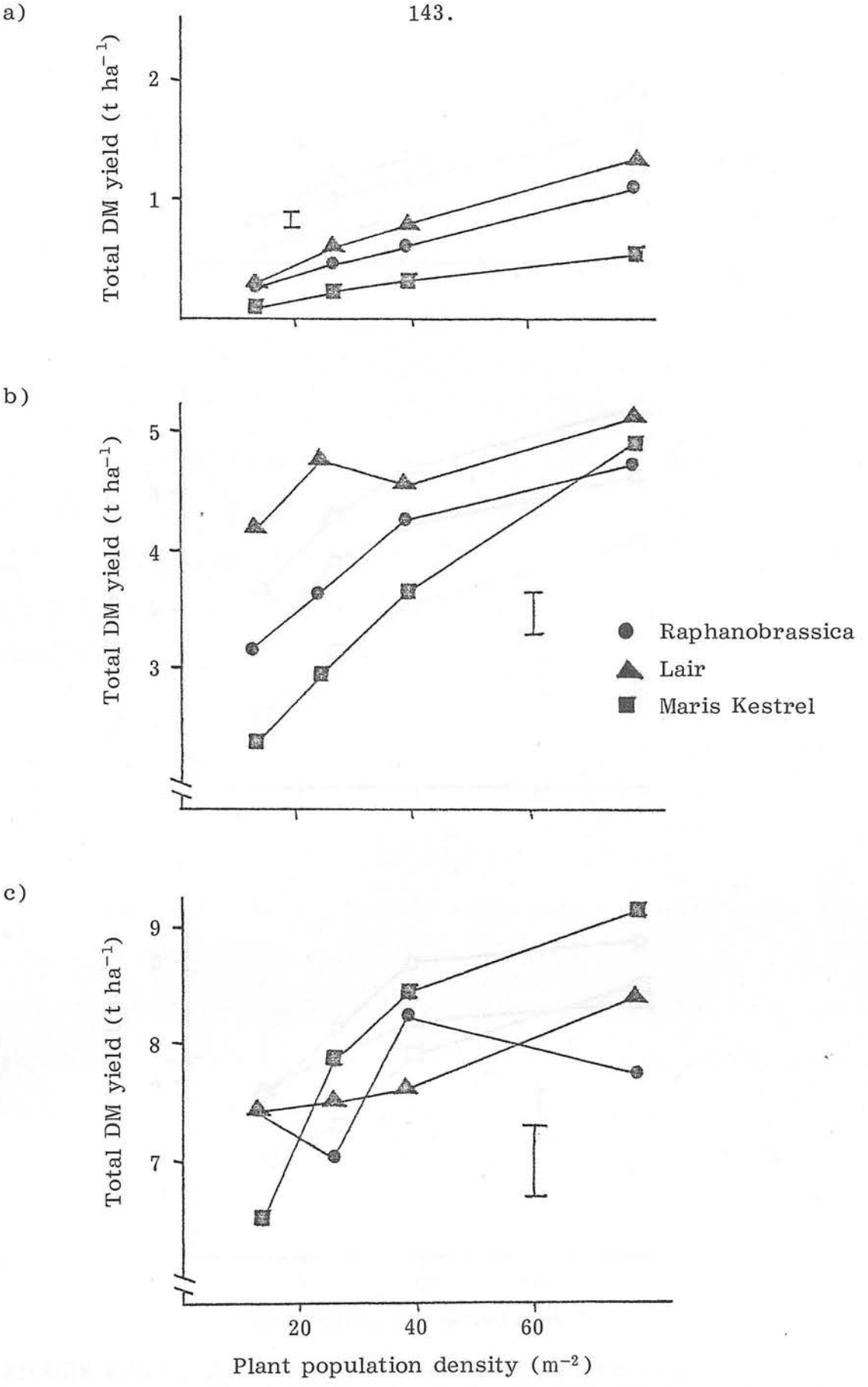


FIGURE 6.3.2: Total dry matter yield 1980. June sowing:
a) 4 August harvest; b) 1 September harvest;
c) 20 October harvest.

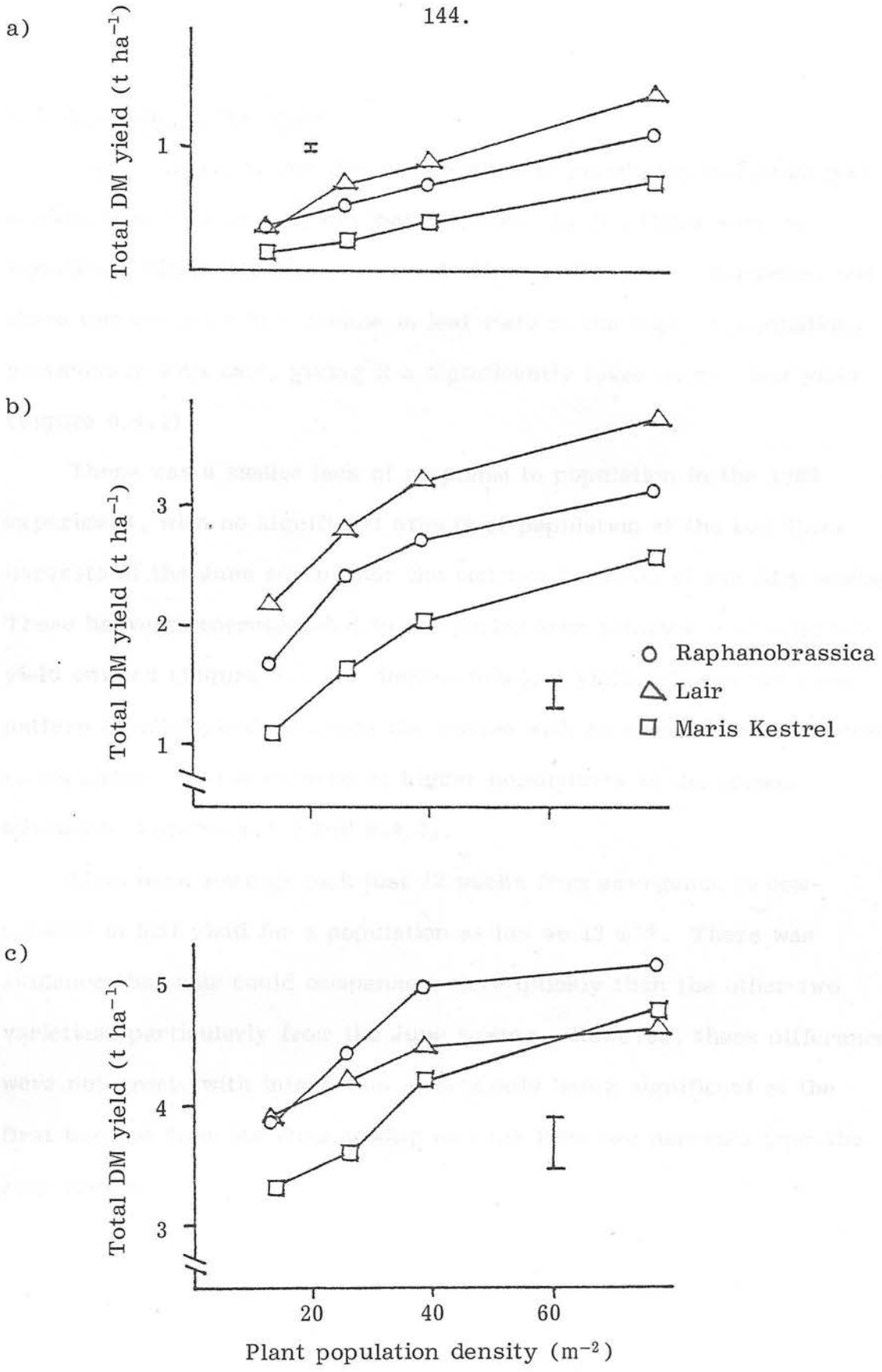


FIGURE 6.3.3: Total dry matter yield 1980. July sowing:
a) 1 September harvest; b) 22 September harvest;
c) 20 October harvest.

6.4 Leaf Dry Matter Yield

The response of leaf dry matter yield to population was much less marked than that of total dry matter yield. In fact there were no significant differences between populations in the 1979 experiment, but there was evidence of a decline in leaf yield at the highest population, particularly with Lair, giving it a significantly lower overall leaf yield (Figure 6.4.1).

There was a similar lack of response to population in the 1980 experiment, with no significant effects of population at the last three harvests of the June sowing nor the last two harvests of the July sowing. These harvests corresponded to the period from attainment of maximum yield onward (Figure 4.3.4). Before this leaf yield followed the same pattern as total yield, starting the season with an almost linear response to population, which reduced at higher populations as the season advanced (Figures 6.4.2 and 6.4.3).

Thus both sowings took just 12 weeks from emergence to compensate in leaf yield for a population as low as 13 m^{-2}. There was evidence that Lair could compensate more quickly than the other two varieties, particularly from the June sowing. However, these differences were not great, with interaction effects only being significant at the first harvest from the June sowing and the first two harvests from the July sowing.

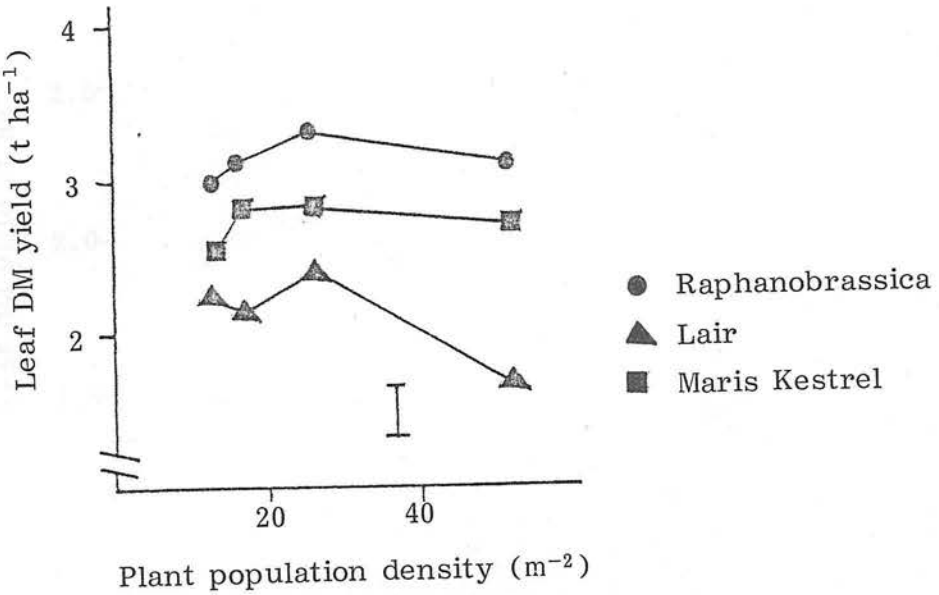


FIGURE 6.4.1: Leaf dry matter yield 1979.

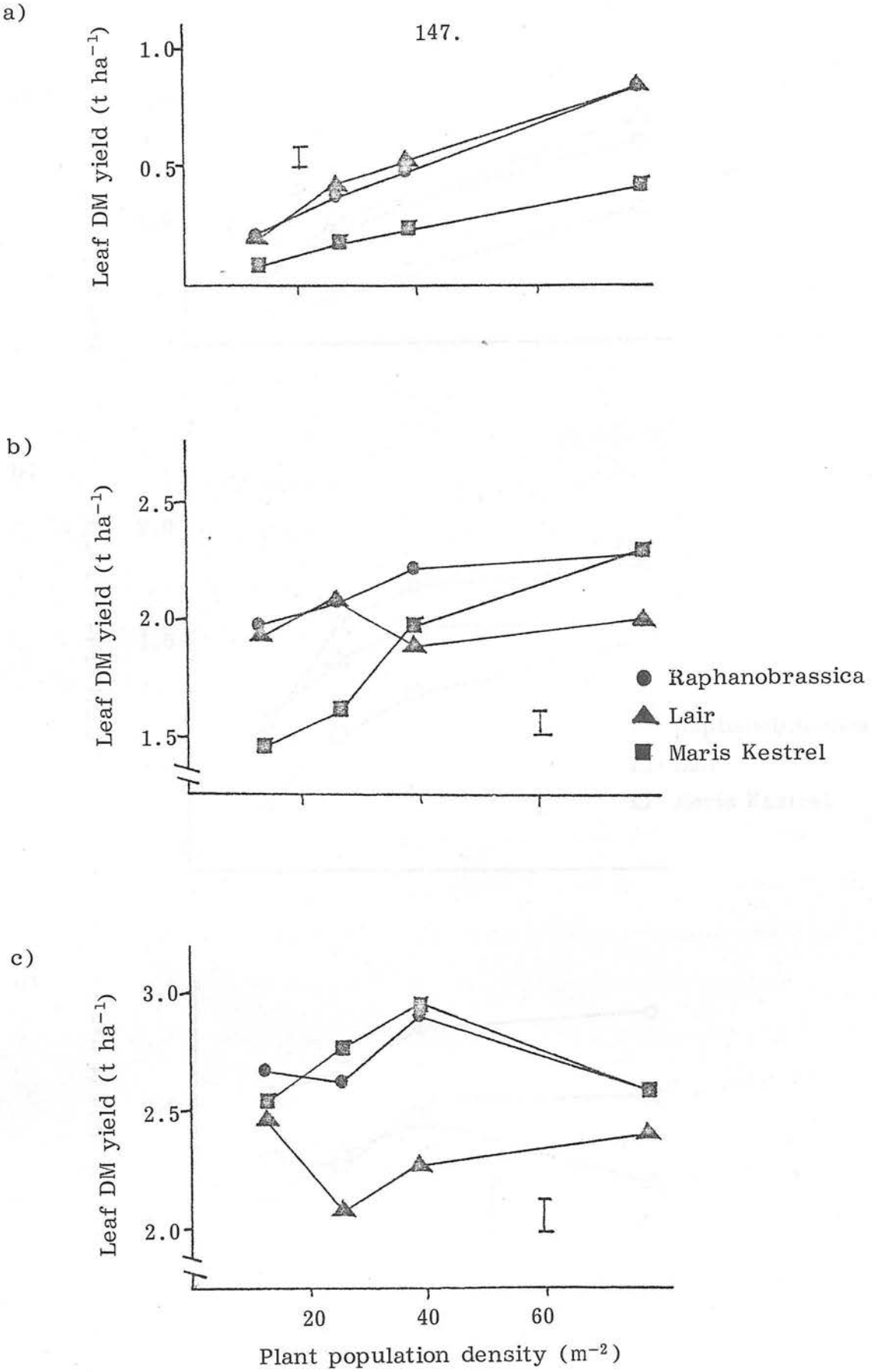


FIGURE 6.4.2: Leaf dry matter yield 1980. June sowing:
a) 4 August harvest; b) 1 September harvest;
c) 10 October harvest.

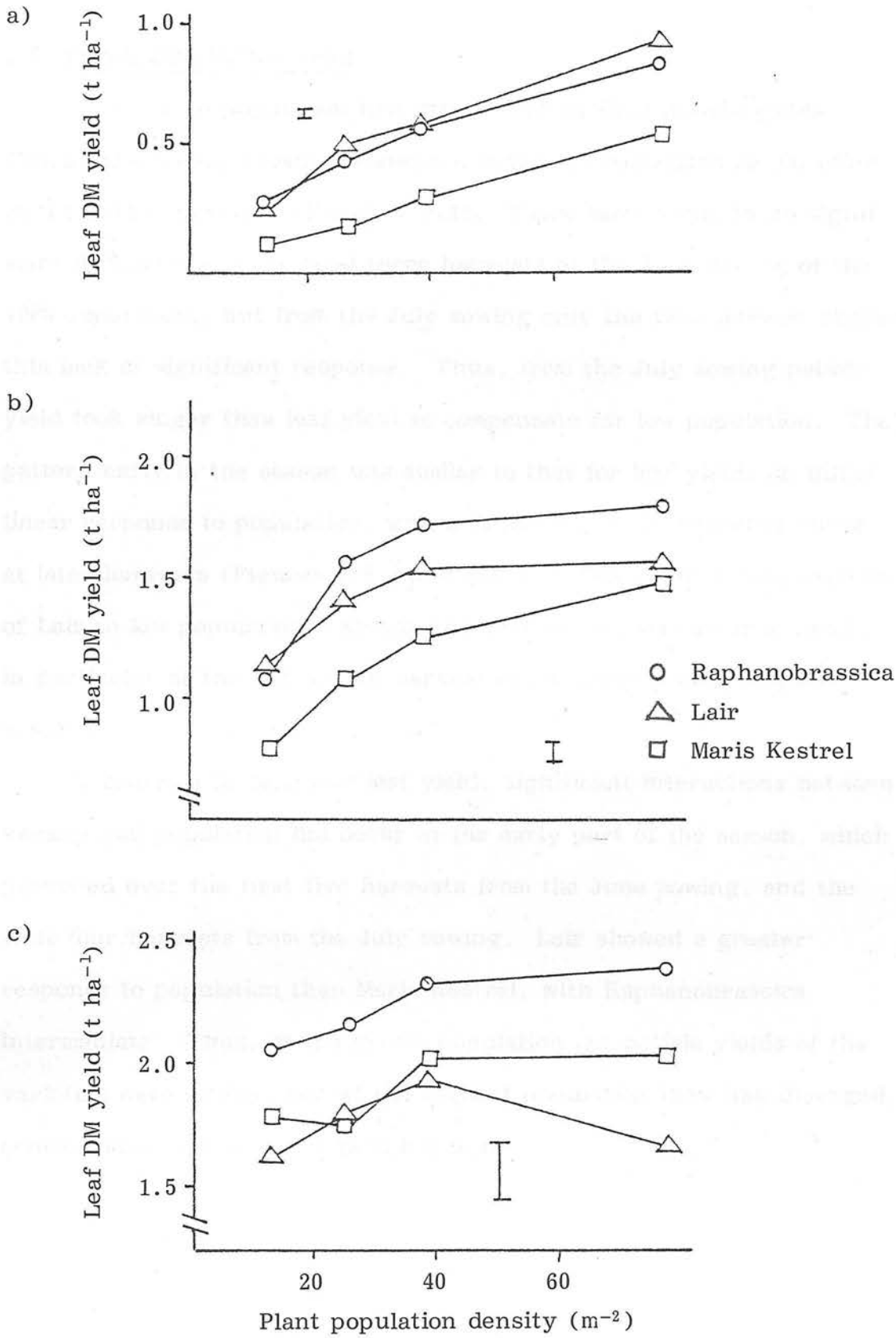


FIGURE 6.4.3: Leaf dry matter yield 1980. July sowing:
a) 1 September harvest; b) 22 September harvest;
c) 20 October harvest.

6.5 Petiole Dry Matter Yield

Variation in population had little effect on final petiole yields. There were no significant differences between populations or varieties in the 1979 experiment (Figure 6.5.1). There were similarly no significant differences at the final three harvests of the June sowing of the 1980 experiment, but from the July sowing only the final harvest showed this lack of significant response. Thus, from the July sowing petiole yield took longer than leaf yield to compensate for low population. The pattern early in the season was similar to that for leaf yield, an initial linear response to population, with a flattening of the response curve at later harvests (Figures 6.5.2 and 6.5.3). The quicker compensation of Lair to low populations, shown with leaf yields, was again evident, in particular at the mid-season harvest of the June sowing (Figure 6.5.2b).

In contrast to total and leaf yield, significant interactions between variety and population did occur in the early part of the season, which persisted over the first five harvests from the June sowing, and the first four harvests from the July sowing. Lair showed a greater response to population than Maris Kestrel, with Raphanobrassica intermediate. Thus, at the lowest population the petiole yields of the varieties were similar, but at the highest population they had diverged considerably (Figures 6.5.2a and 6.5.3a).

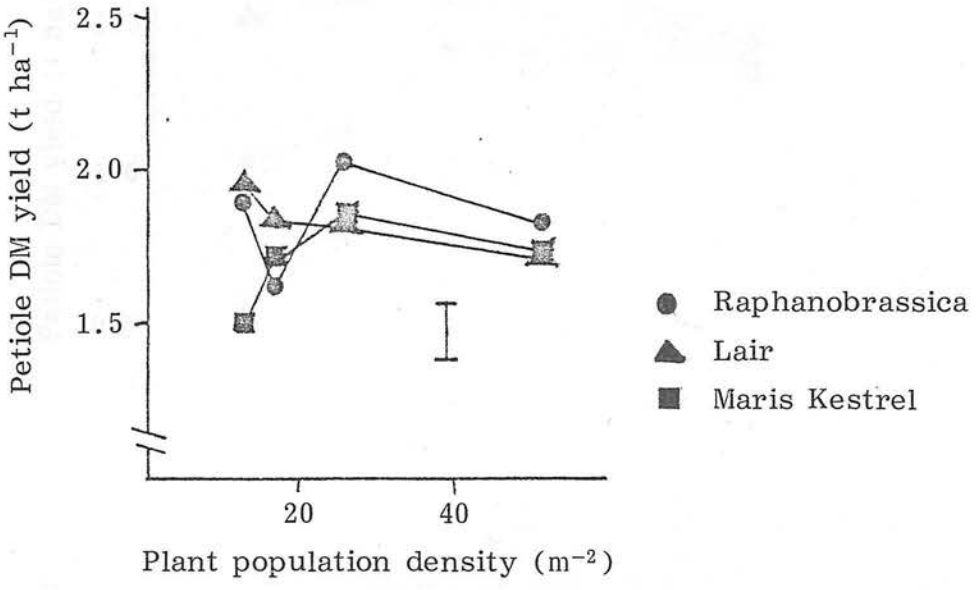


FIGURE 6.5.1: Petiole dry matter yield 1979.

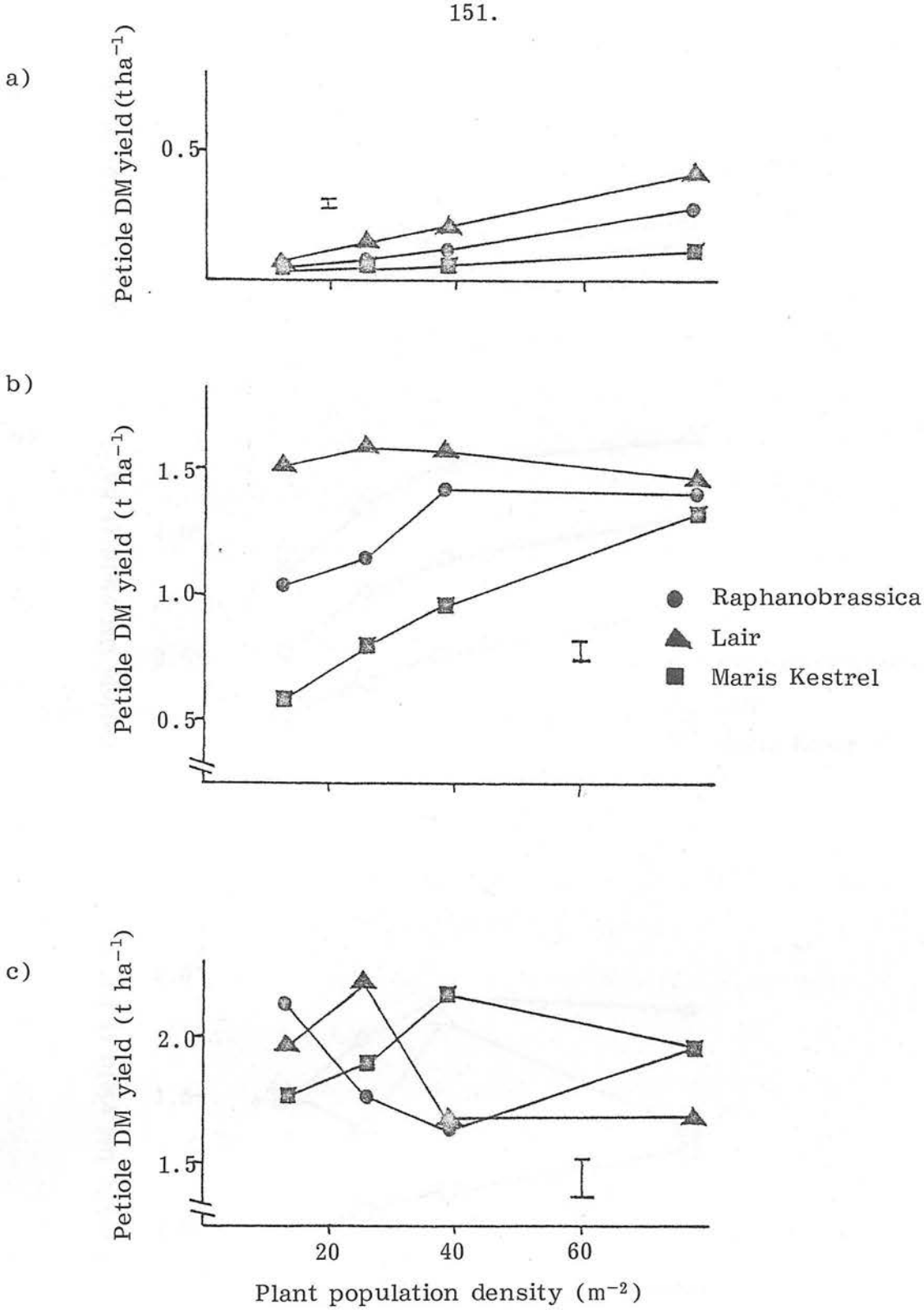


FIGURE 6.5.2: Petiole dry matter yield 1980. June sowing:
a) 4 August harvest; b) 1 September harvest;
c) 20 October harvest.

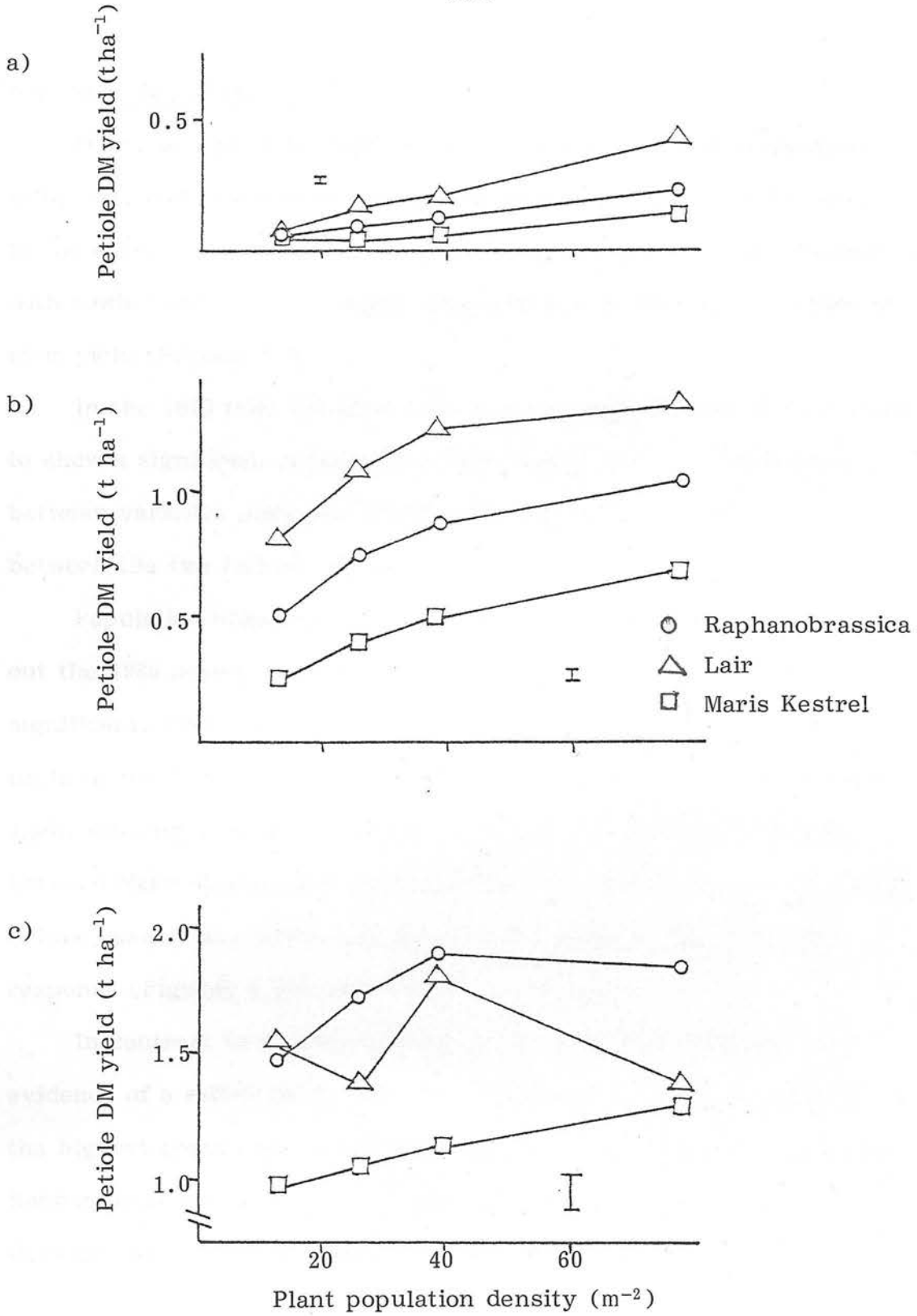


FIGURE 6.5.3: Petiole dry matter yield 1980. July sowing:
a) 1 September harvest; b) 22 September harvest
c) 20 October harvest.

6.6 Stem Dry Matter Yield

It was on the stem fraction that population exerted its greatest influence, and it was thus differences in stem that contributed most to the effects on total yield noted. This is analagous to the situation with sowing date effects, which were also mostly due to differences in stem yield (Section 4.5).

In the 1979 trial the stem yield was the only fraction of total yield to show a significant population effect (Figure 6.6.1). Differences between varieties were also significant, but again the interaction between the two factors was not.

Population effects were also highly significant ($P < 0.001$) throughout the 1980 season, and as with petiole yield, interaction was also significant, over the first three harvests from the June sowing, and up until the final harvest from the July sowing. This was due to Lair again showing a greater response to population, but the difference between Maris Kestrel and Raphanobrassica was less marked than with petiole, and it was Raphanobrassica that tended to show the least response (Figures 6.6.2 and 6.6.3).

In contrast to leaf and petiole, with stem yield there was little evidence of a reduction in response as the season advanced, except at the highest population at the later harvests. The reduction shown by Raphanobrassica at the highest population from the June sowing at the October harvest did not appear at the following, final harvest.

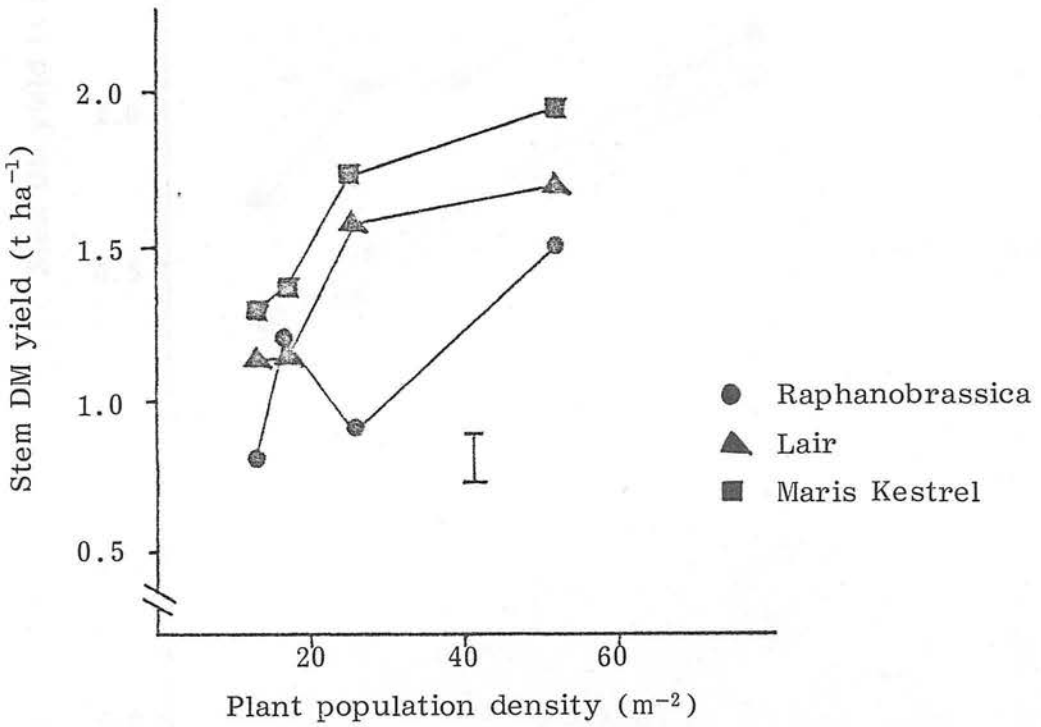


FIGURE 6.6.1: Stem dry matter yield 1979.

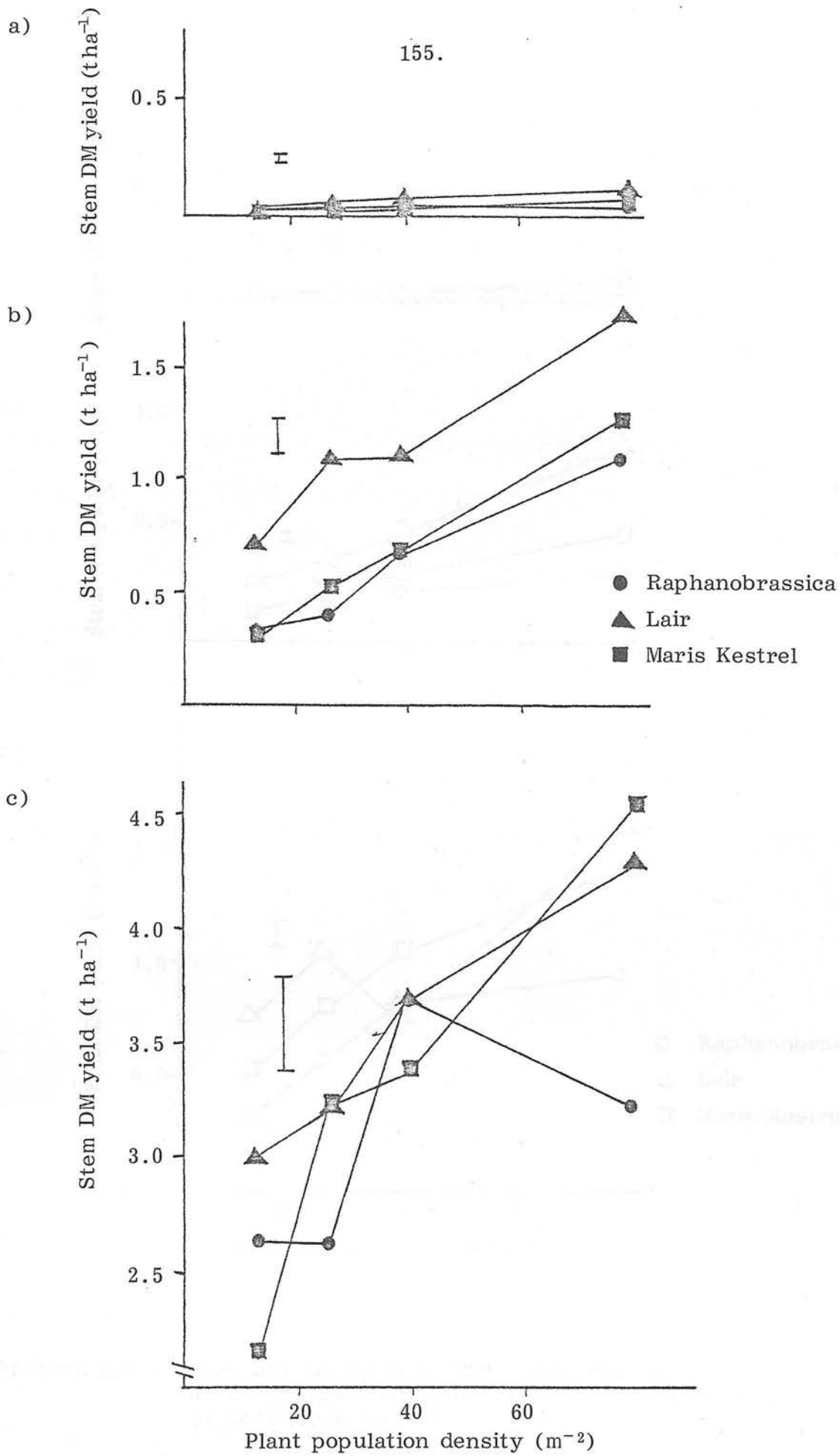


FIGURE 6.6.2: Stem dry matter yield 1980. June sowing:
a) 4 August harvest; b) 1 September harvest;
c) 20 October harvest.

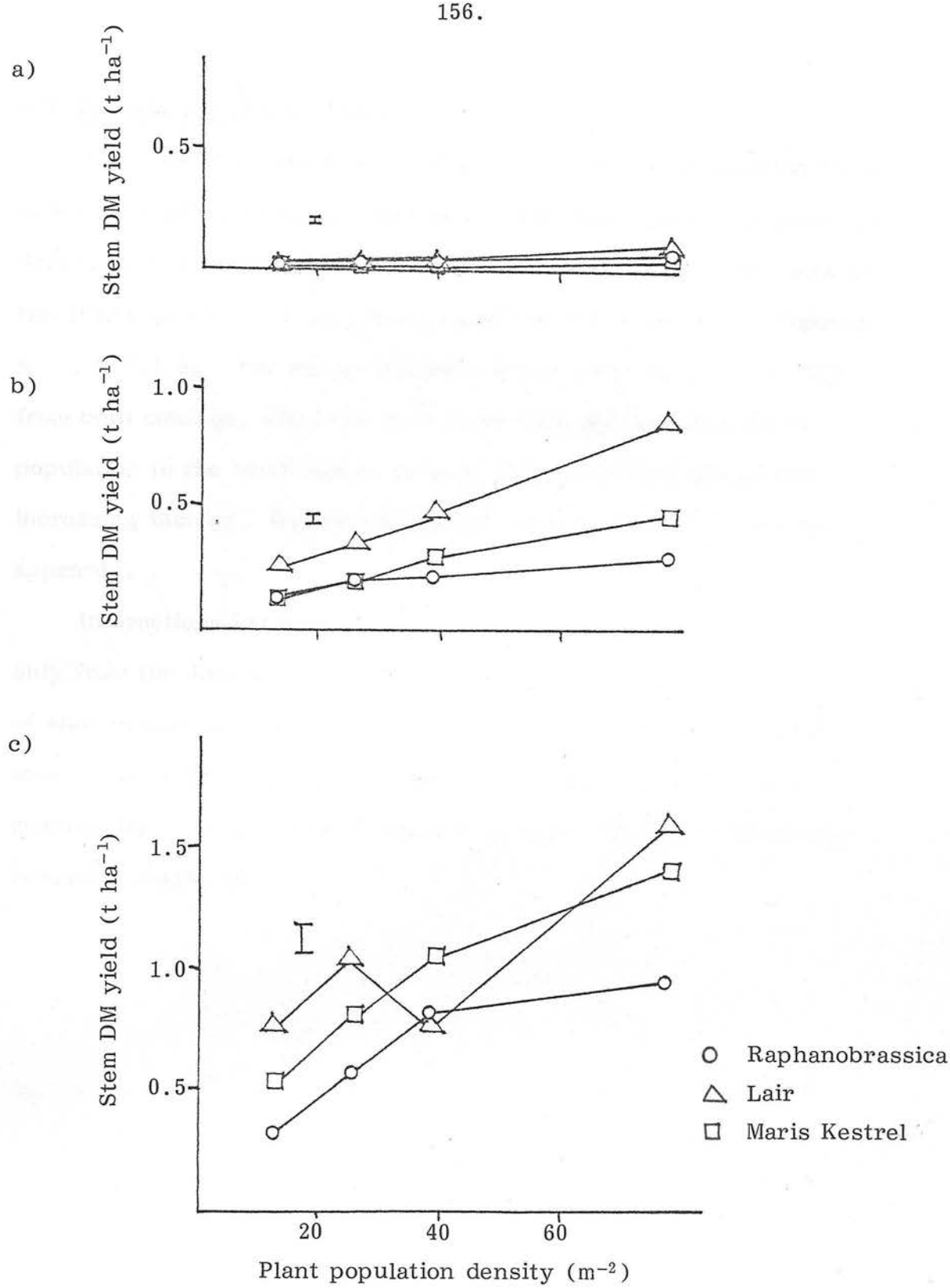


FIGURE 6.6.3: Stem dry matter yield 1980. July sowing:
a) 1 September harvest; b) 22 September harvest;
c) 20 October harvest.

6.7 Partitioning of Dry Matter

These results showed that, in general, the stem proportion tended to increase with increasing plant population, leaf proportion tended to decrease, and that of petiole tended to remain more constant, both in the 1979 experiment (Figure 6.7.1) and the 1980 experiment (Figures 6.7.2 to 6.7.5). The exceptions were at the early harvests in 1980, from both sowings, when the stem proportion did not respond to population to the same degree as leaf, with the petiole proportion increasing instead. By the mid-season harvest this effect had disappeared.

Interactions between variety and population were significant only from the July sowing in the mid-season period. Here the proportion of stem in Lair increased more with population, and Raphanobrassica less so, with Maris Kestrel intermediate. These differences were matched by corresponding changes in petiole proportion, whilst leaf remained unaffected.

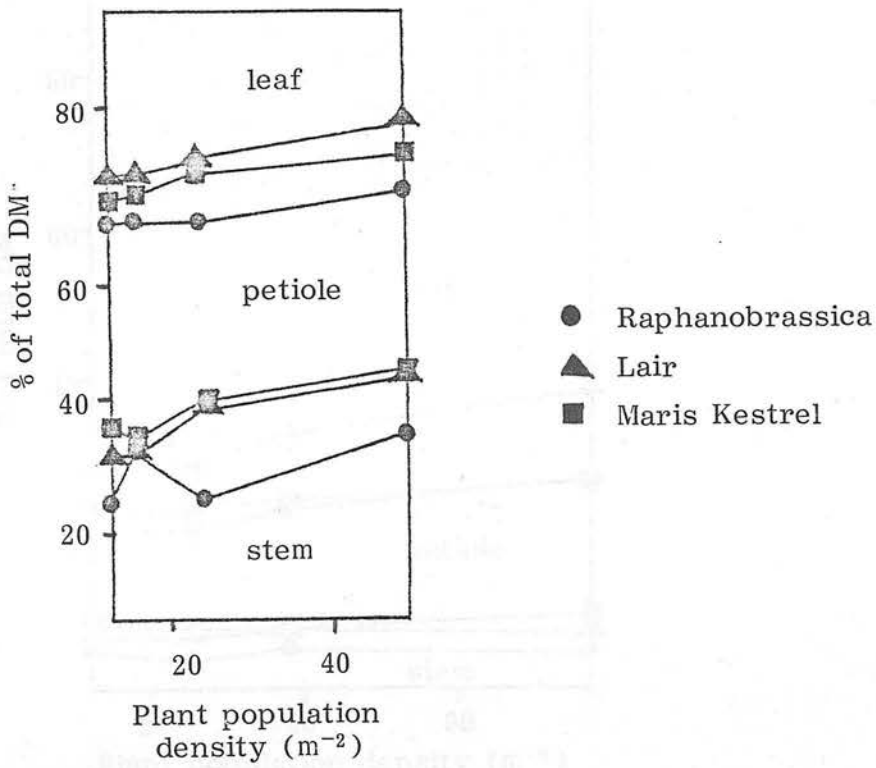


FIGURE 6.7.1: Partitioning of dry matter 1979.

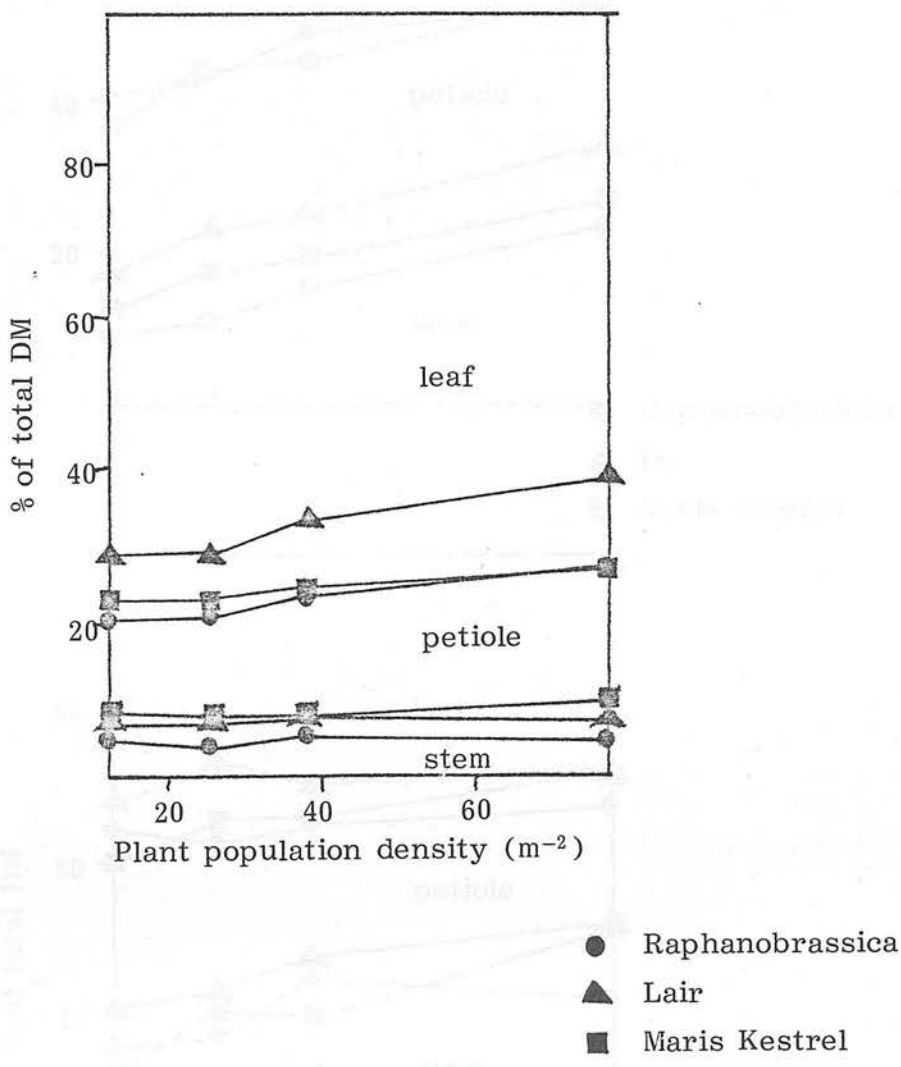


FIGURE 6.7.2: Partitioning of dry matter 1980. June sowing (4 August harvest).

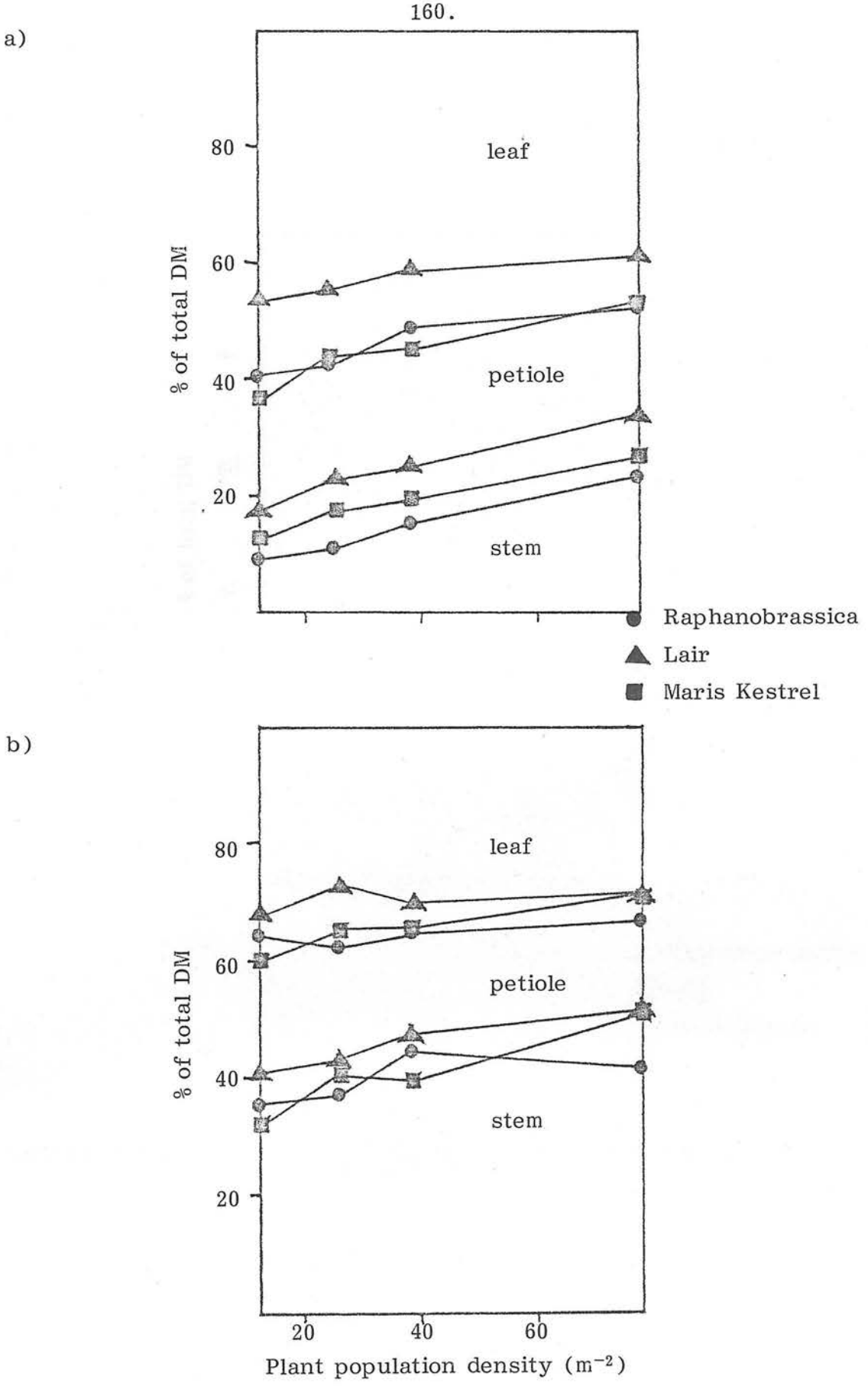


FIGURE 6.7.3: Partitioning of dry matter 1980. June sowing: a) 1 September harvest; b) 20 October harvest.

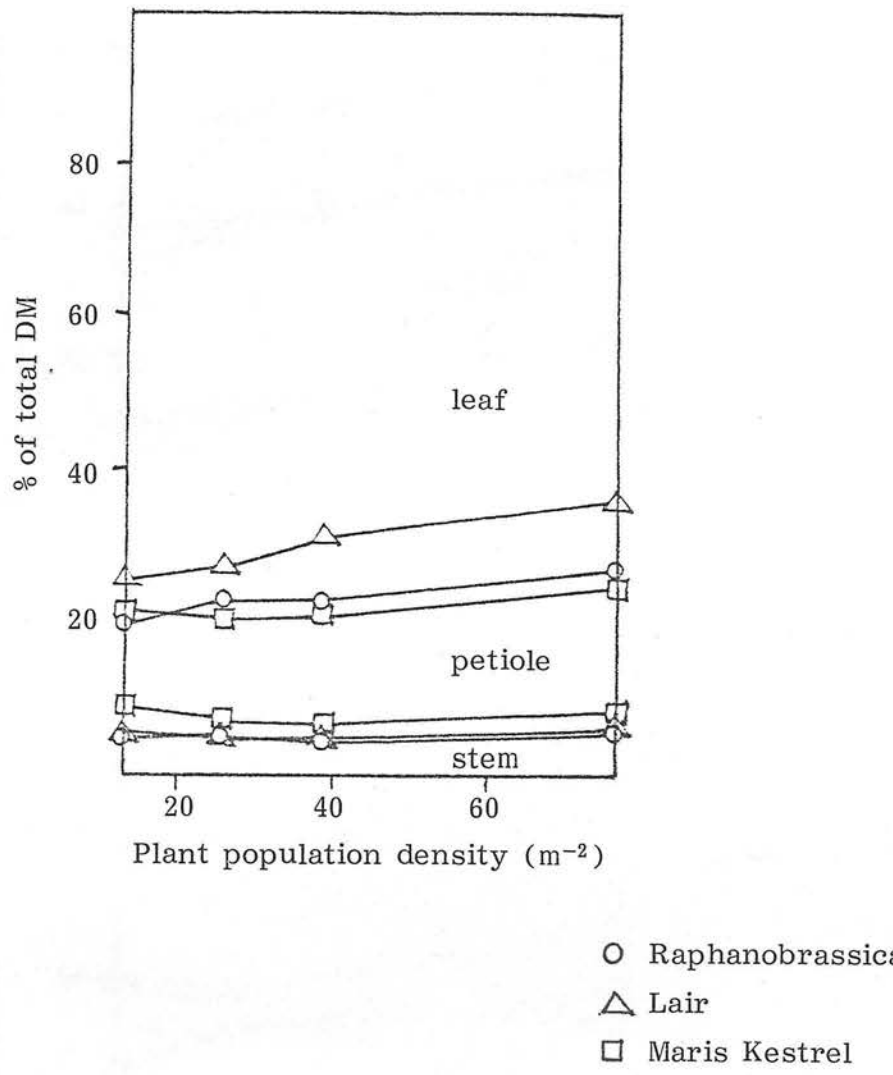


FIGURE 6.7.4: Partitioning of dry matter 1980. July sowing (1 September harvest).

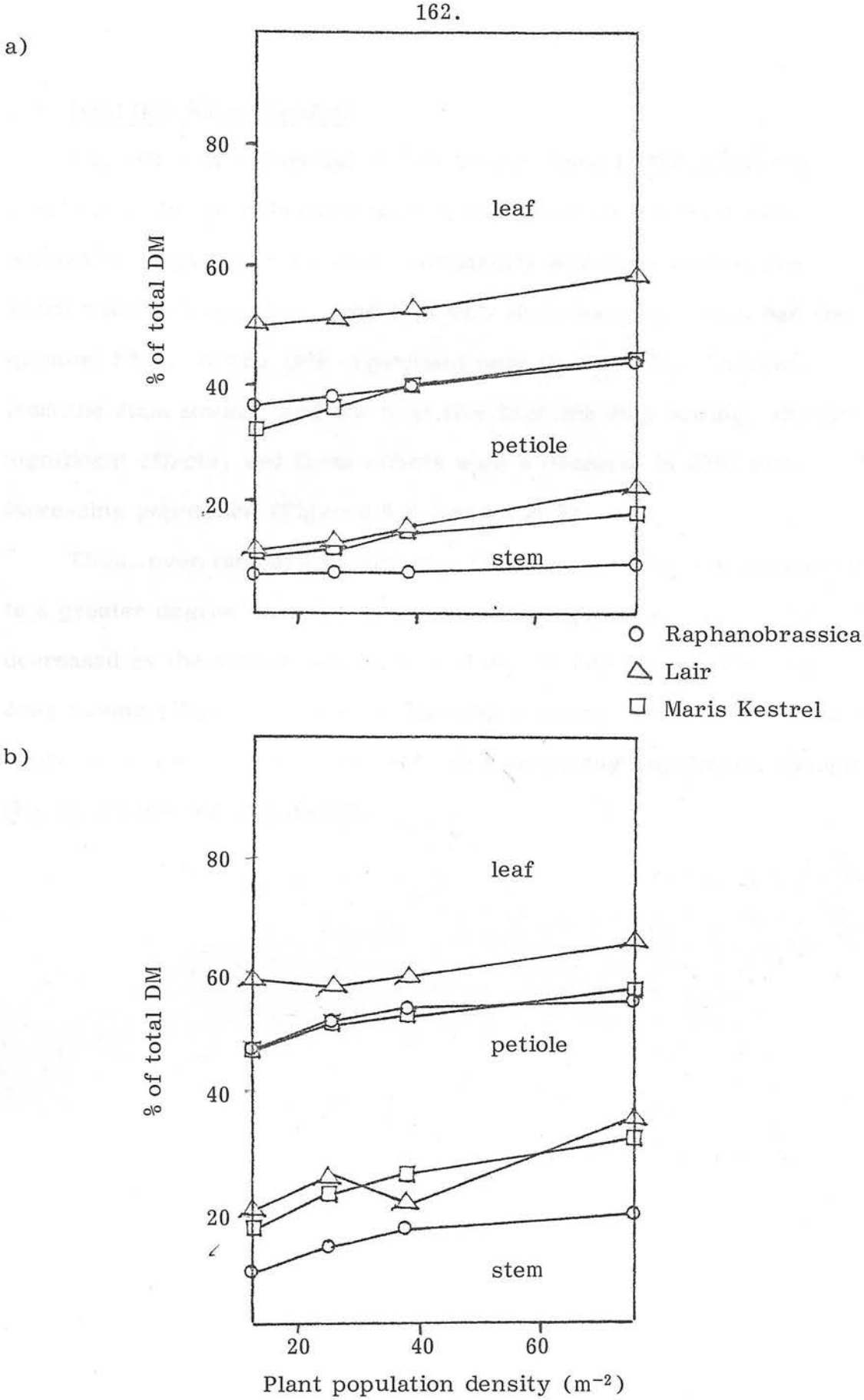


FIGURE 6.7.5: Partitioning of dry matter 1980. July sowing:
a) 22 September harvest; b) 20 October harvest.

6.8 Total Dry Matter Content

The effect of population on Dry Matter Content (DMC) was less consistent. In the 1979 experiment it increased significantly with population (Figure 6.8.1), most consistently with Raphanobrassica, which had the lowest DMC, and less with Maris Kestrel, which had the greatest DMC. In the 1980 experiment only the first four harvests from the June sowing, and the first five from the July sowing, showed significant effects, and these effects were a decrease in DMC with increasing population (Figures 6.8.2 and 6.8.3).

Thus, over the earlier harvests, fresh matter yield was responding to a greater degree than dry matter yield to population. This effect decreased as the season advanced, and by the late harvest from the June sowing (Figure 6.8.2c) was showing a similar tendency to the 1979 experiment, i.e. an increasing DMC with increasing population, though this effect was not significant.

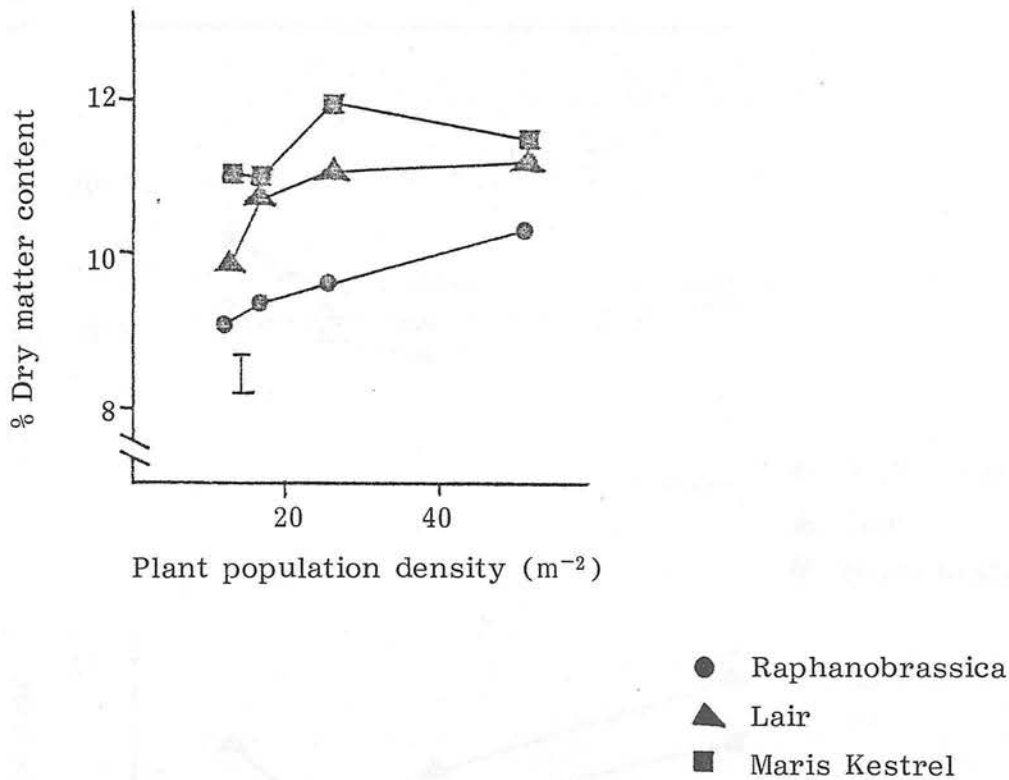


FIGURE 6.8.1: Total dry matter content 1979.

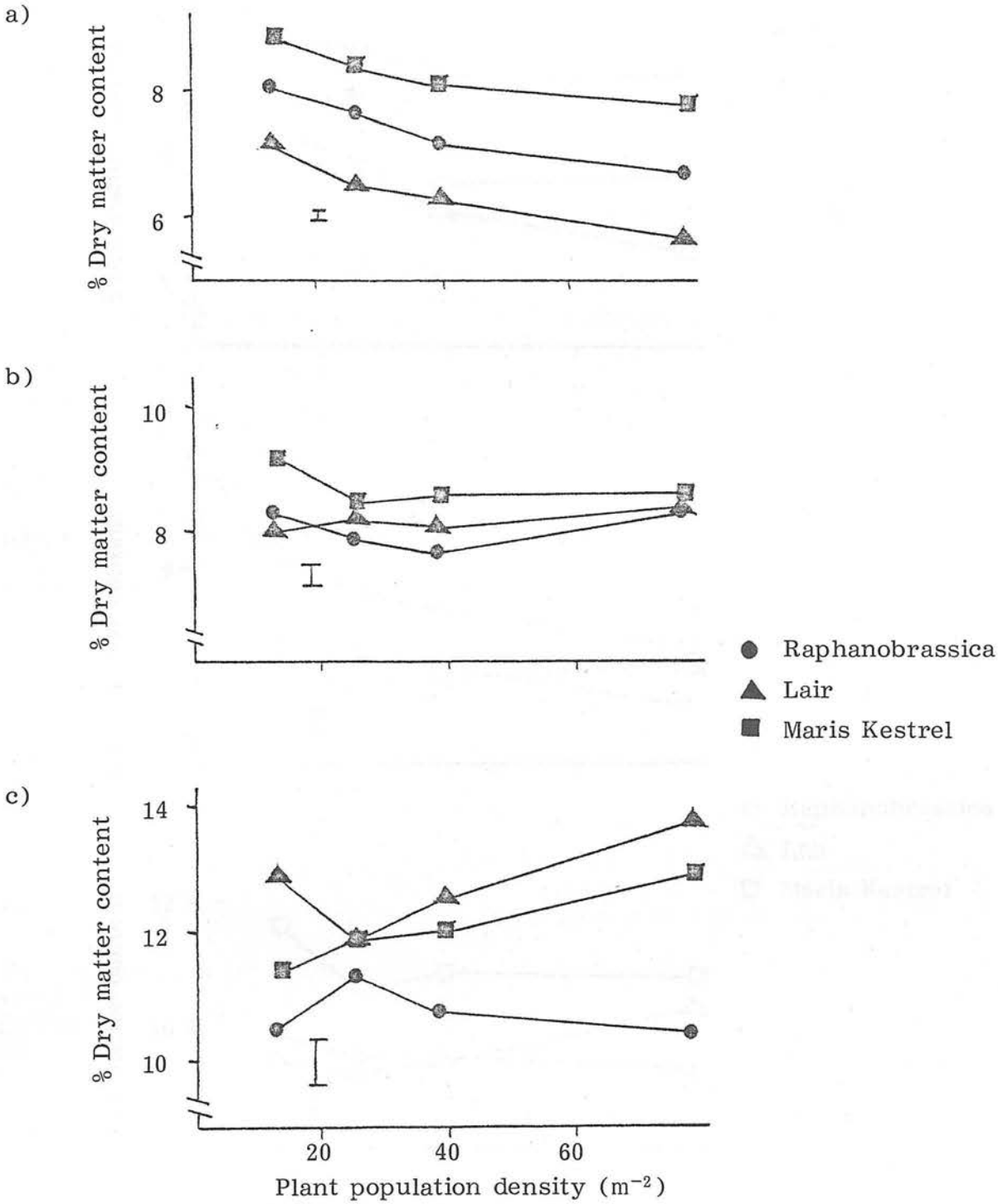


FIGURE 6.8.2: Total dry matter content 1980. June sowing:
a) 4 August harvest; b) 1 September harvest;
c) 20 October harvest.

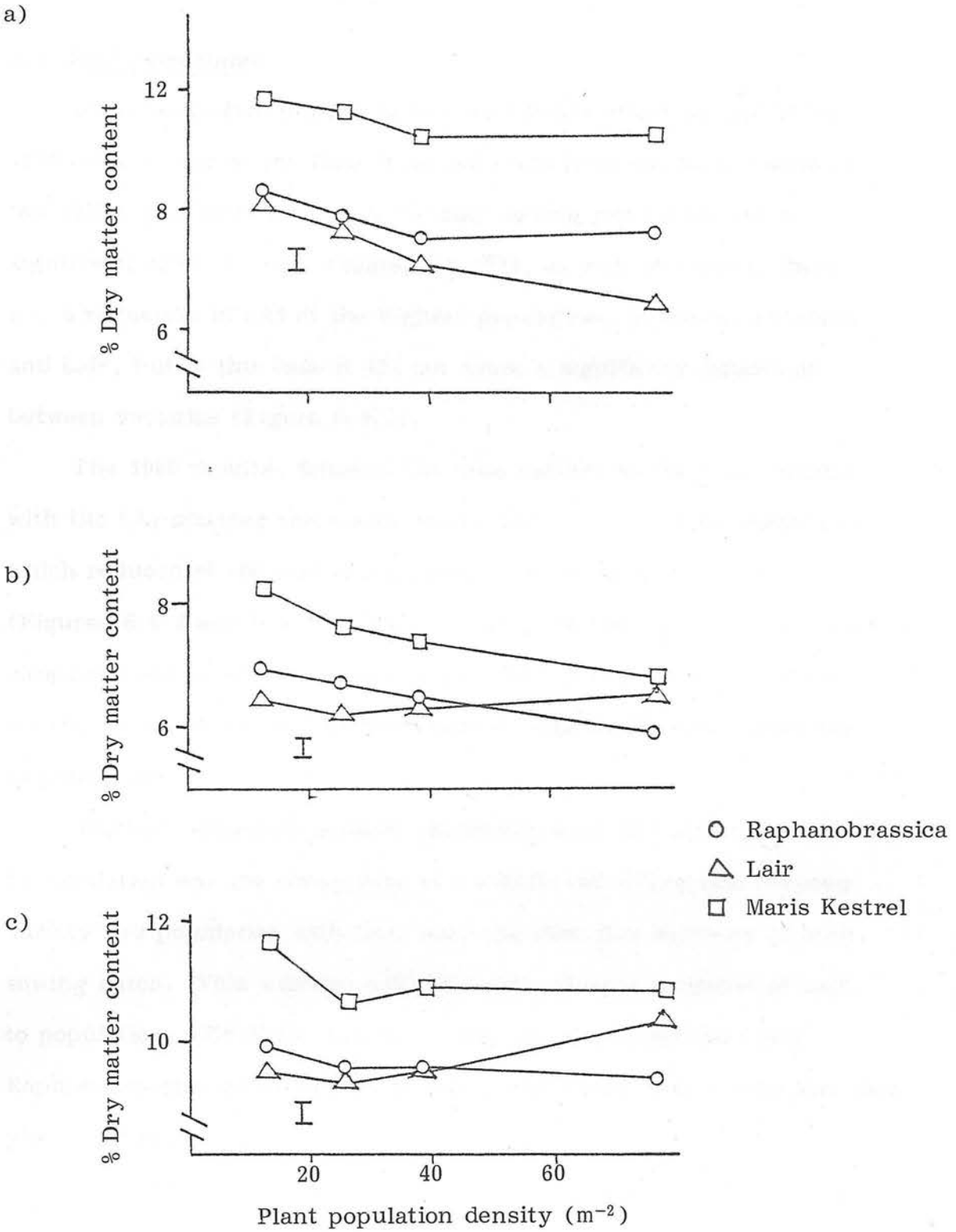


FIGURE 6.8.3: Total dry matter content 1980. July sowing:
a) 1 September harvest; b) 22 September harvest;
c) 20 October harvest.

6.9 Leaf Area Index

Plant population did not have a significant effect on LAI in the 1979 results, nor at the final three harvests from the June sowing of the 1980 trial. However, from the July sowing population had a significant effect at all harvests. In 1979, as with leaf yield, there was a reduction in LAI at the highest population, in Raphanobrassica and Lair, but in this case it did not cause a significant difference between varieties (Figure 6.9.1).

The 1980 results, followed the same pattern as the yield results, with the LAI starting the season with a linear response to population, which reduced at the higher populations as the season advanced (Figures 6.9.2 and 6.9.3). Both the initial response and the subsequent compensations were more marked than with either total or leaf yield. By the time of maximum LAI there were no significant differences due to population.

Another difference between the response of LAI and leaf yield to population was the occurrence of a significant interaction between variety and population with LAI, over the first five harvests of both sowing dates. This was due initially to the greater response of Lair to population, with Maris Kestrel having the least response, and Raphanobrassica intermediate, a feature also noted with petiole and stem yield, but not leaf yield.

From the June sowing, by the beginning of September, Lair had compensated in LAI for population completely, whilst Maris Kestrel and Raphanobrassica had only done so at the highest population. From the July sowing LAI showed a significant response over the three lower populations until the end of the season. With the other parameters that reached a maximum value and then declined, leaf and petiole yield,

population had ceased to be a significant factor by the time this maximum was reached. The LAI values reached a maximum in early October from the July sowing (Figure 4.8.4), and then reduced, and thus this was the only instance where population retained an effect on a declining parameter.

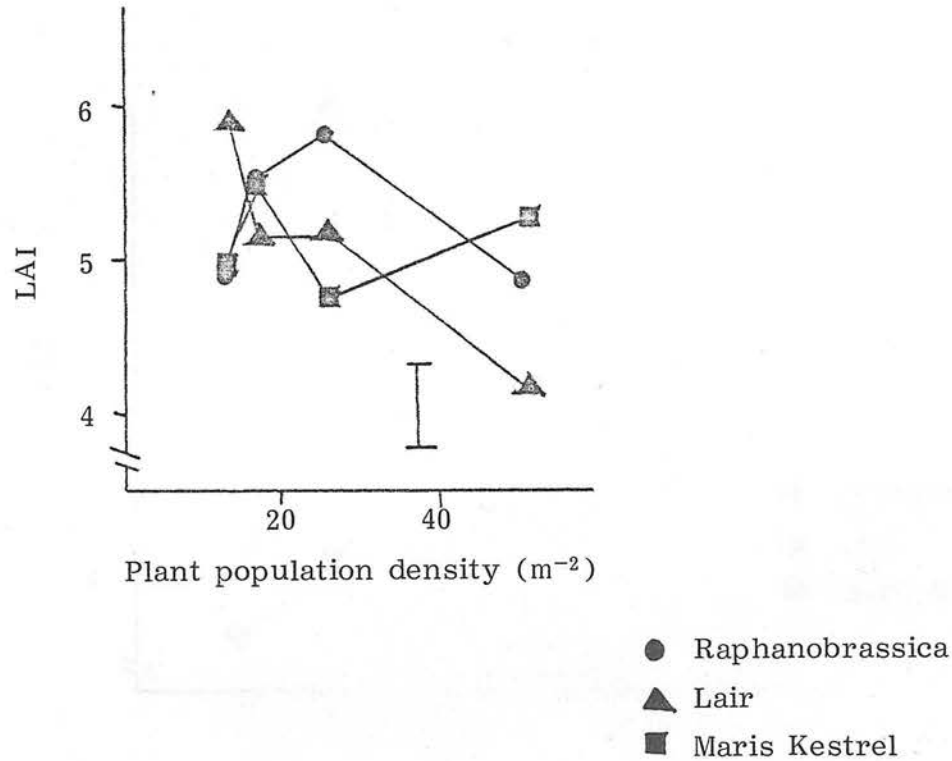


FIGURE 6.9.1: Leaf Area Index 1979.

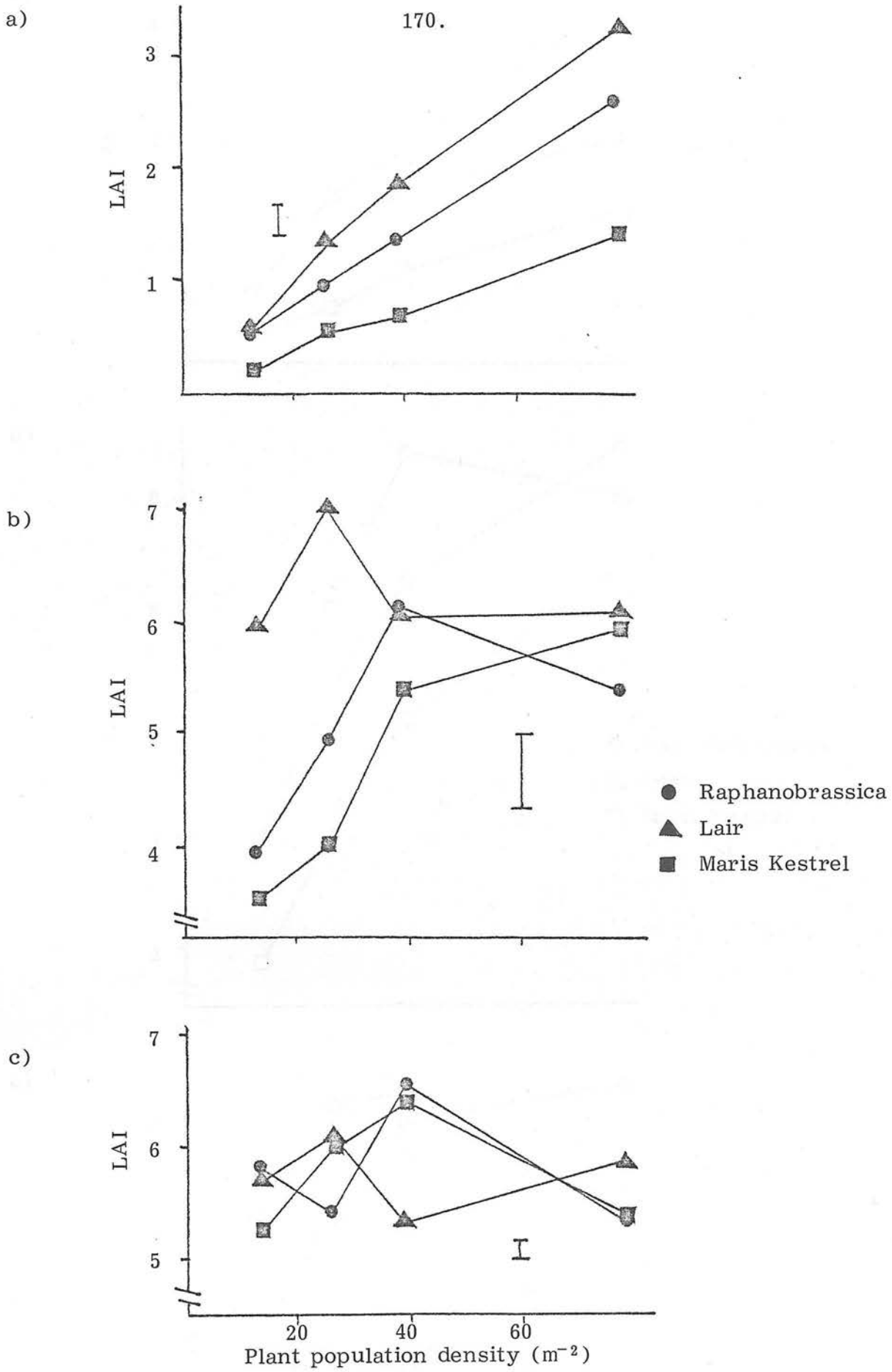


FIGURE 6.9.2: Leaf Area Index 1980. June sowing:
a) 4 August harvest; b) 1 September harvest;
c) 20 October harvest.

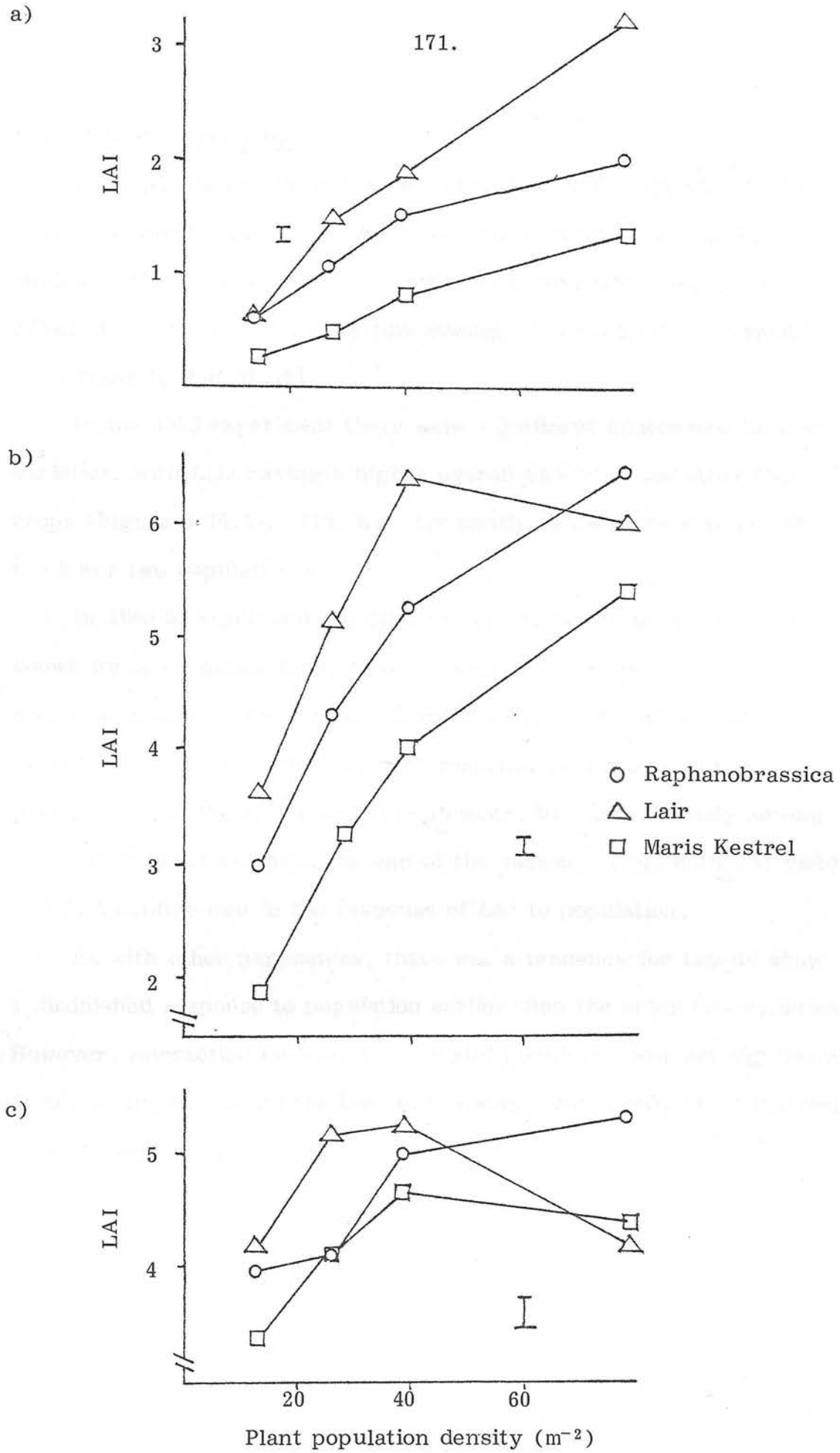


FIGURE 6.9.3: Leaf Area Index 1980. July sowing: a) 1 September harvest; b) 22 September harvest; c) 20 October harvest.

6.10 Specific Leaf Area

Plant population did not have a significant effect on SLA in the 1979 experiment, and only at the first four harvests from the June sowing in the 1980 experiment. However, it remained a significant effect at all harvests from the July sowing. This pattern of response was similar to that of LAI.

In the 1979 experiment there were significant differences between varieties, with Lair having a higher overall SLA than the other two crops (Figure 6.10.1). This was due mostly to its greater values at the lower two populations.

In 1980 SLA followed the same pattern of response to population shown by other parameters, a linear response early in the season, which decreased as the season advanced (Figures 6.10.2 and 6.10.3). From the June sowing all significant response to population had disappeared by the beginning of September, but from the July sowing some effect persisted until the end of the season. Thus both leaf yield and SLA contributed to the response of LAI to population.

As with other parameters, there was a tendency for Lair to show a diminished response to population earlier than the other two varieties. However, interaction between variety and population was not significant at any of the harvests from the June sowing, and at only three harvests from the July sowing.

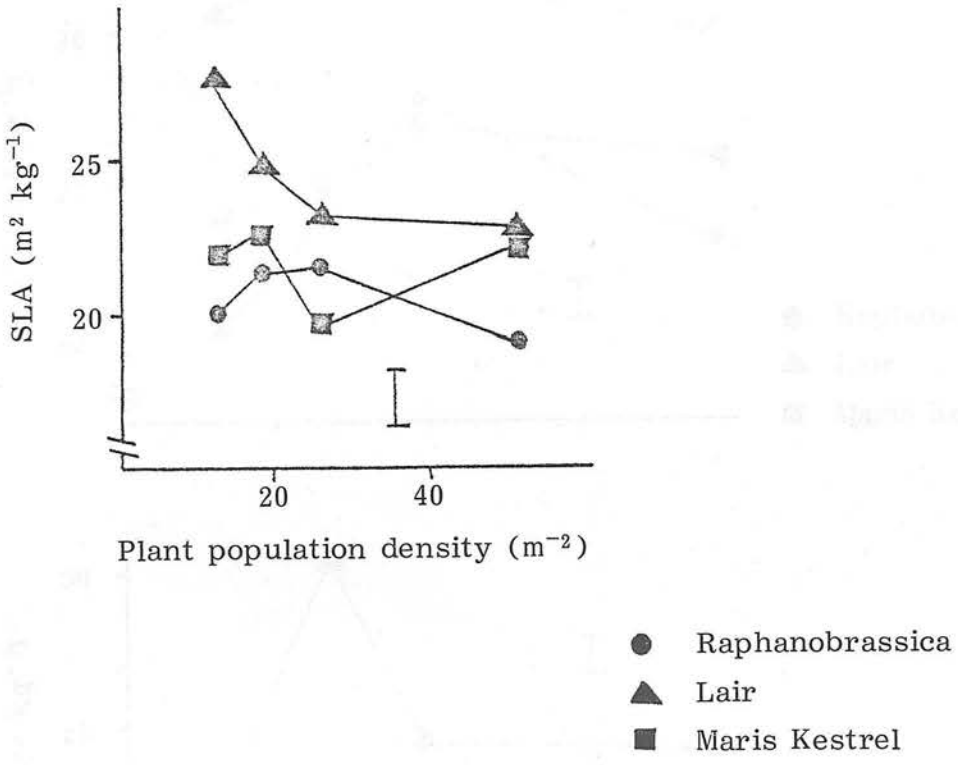


FIGURE 6.10.1: Specific Leaf Area 1979.

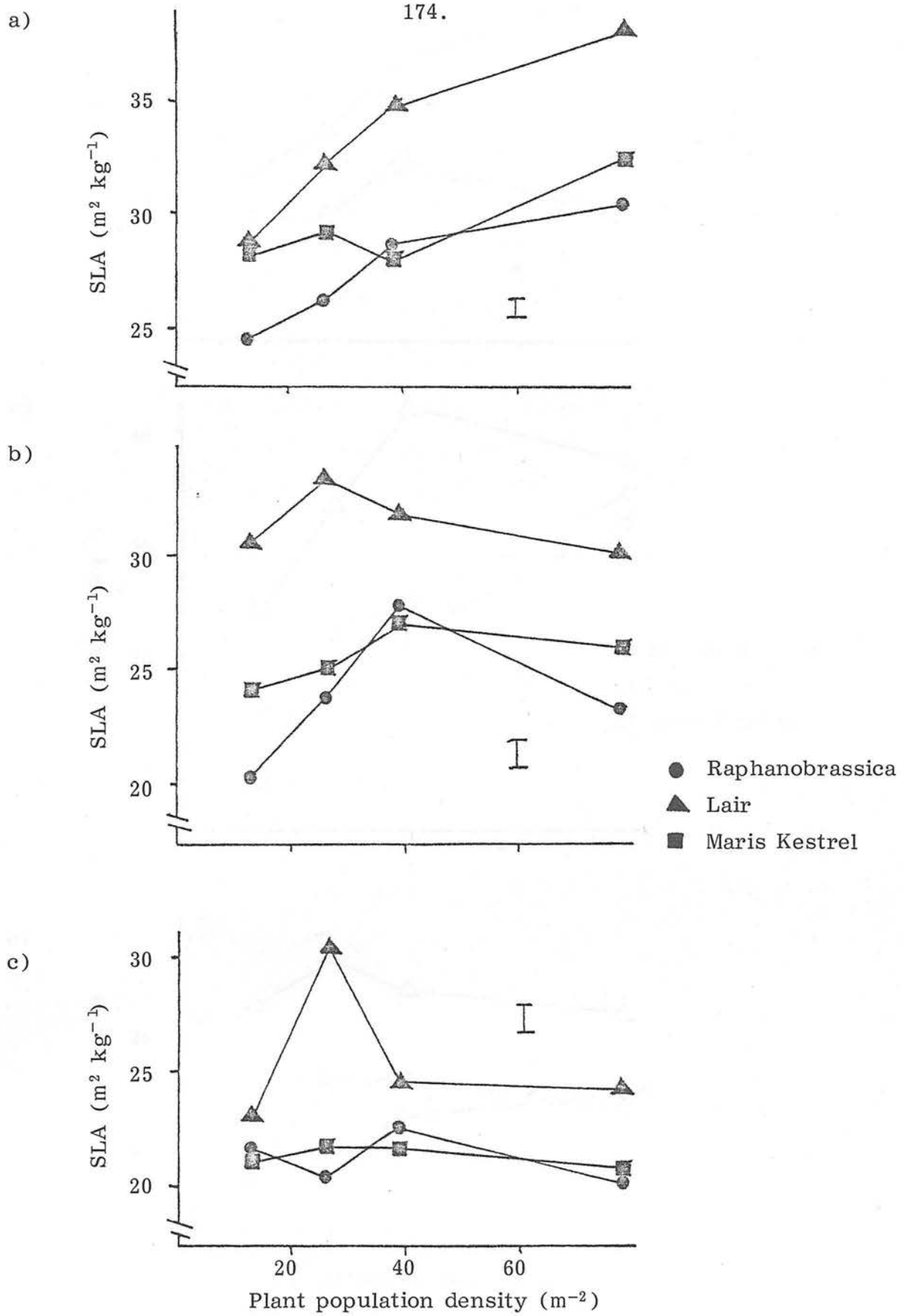


FIGURE 6.10.2: Specific Leaf Area 1980. June sowing:
a) 4 August harvest; b) 1 September harvest;
c) 20 October harvest.

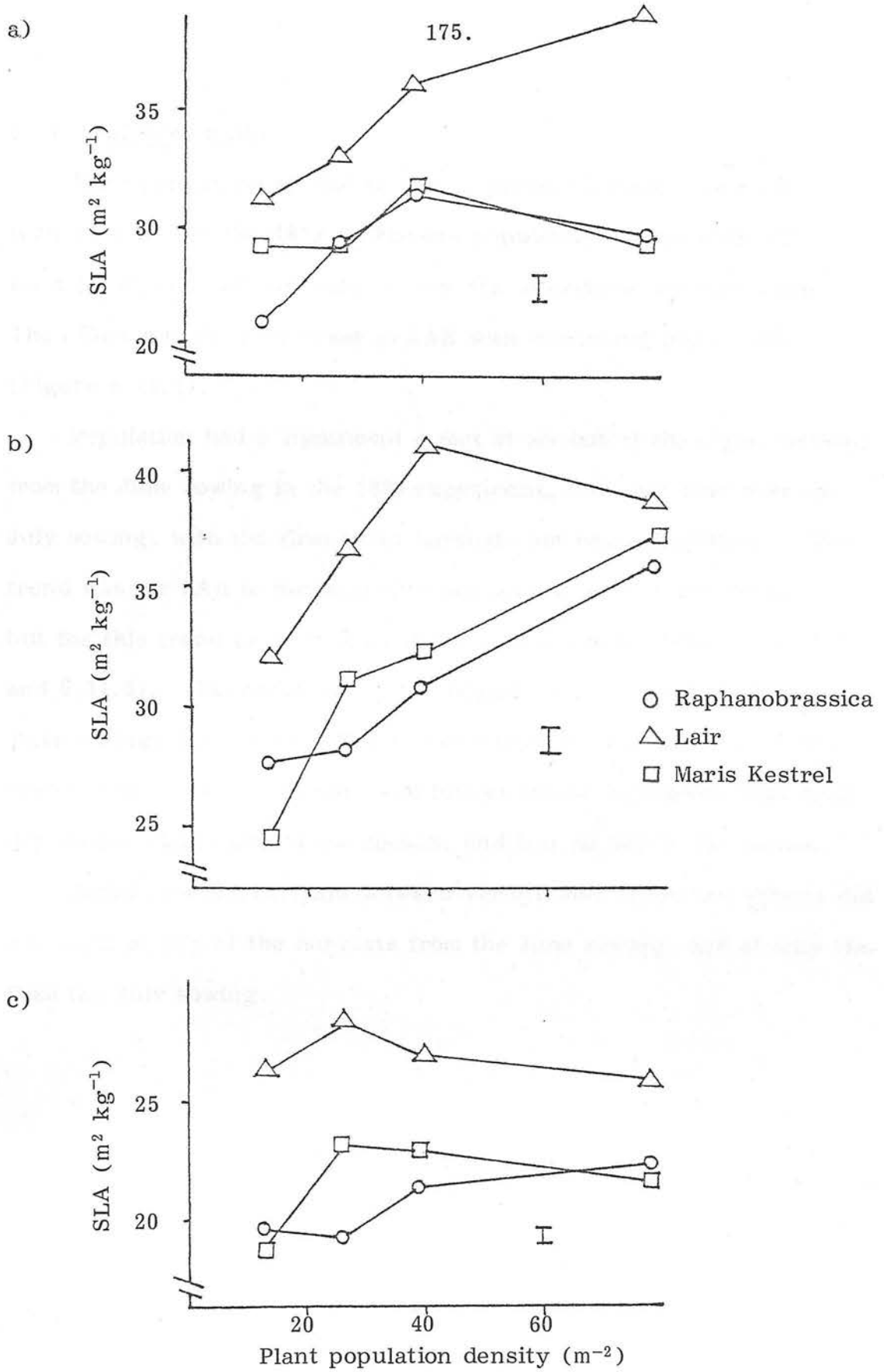


FIGURE 6.10.3: Specific Leaf Area 1980. July sowing:
a) 1 September harvest; b) 22 September harvest;
c) 20 October harvest.

6.11 Leaf Area Ratio

Plant population tended to have a greater influence on LAR than variety. In the 1979 experiment population effects were significant ($P < 0.01$), but not variety, nor the interaction between them. The effect was for a decrease in LAR with increasing population (Figure 6.11.1).

Population had a significant effect at six out of the eight harvests from the June sowing in the 1980 experiment, but only four from the July sowing, with the first three harvests not being significant. The trend was for LAR to increase with population early in the season, but for this trend to reverse as the season advanced (Figures 6.11.2 and 6.11.3). This occurred by the beginning of September from the June sowing, but not until late October from the July sowing. These results indicate that LAI was more influenced by population than total dry matter yield early in the season, and less so late in the season.

Significant interactions between variety and population effects did not occur at any of the harvests from the June sowing, and at only two from the July sowing.

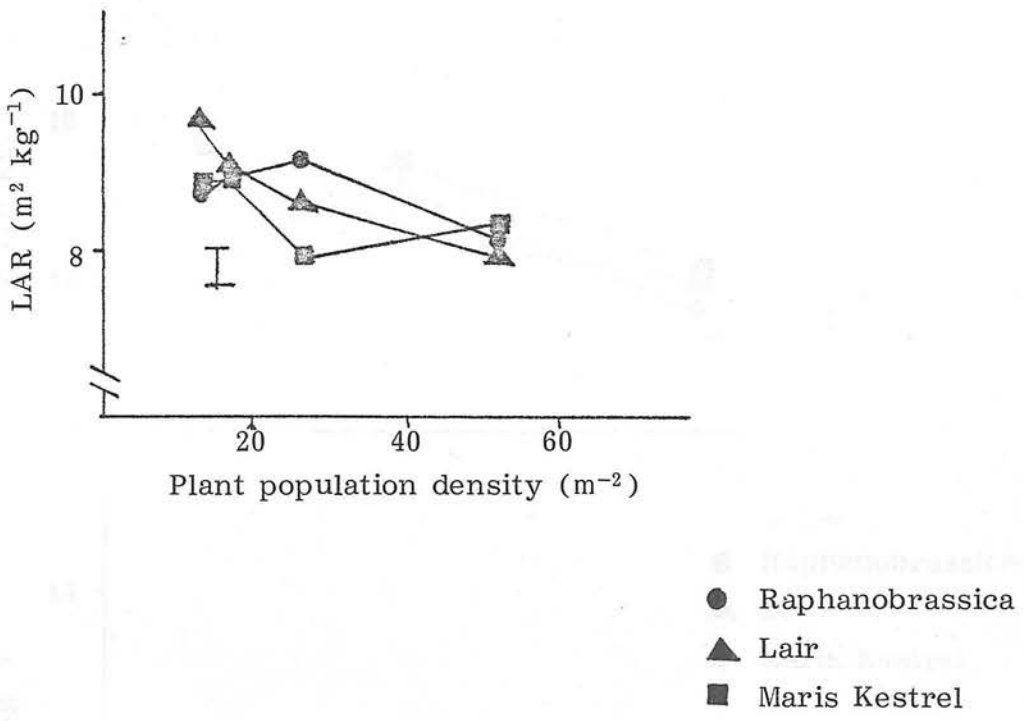


FIGURE 6.11.1: Leaf Area Ratio 1979

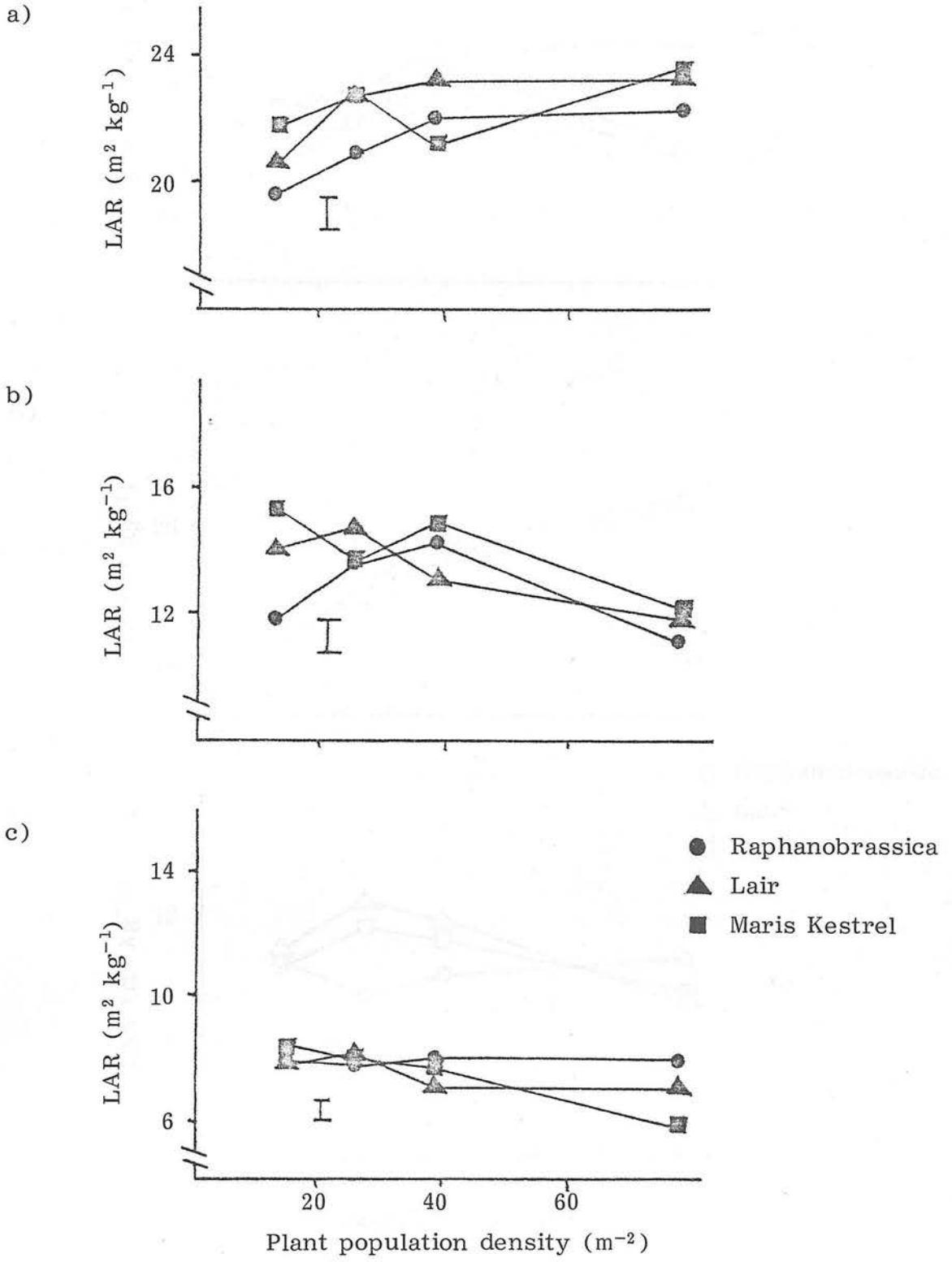


FIGURE 6.11.2: Leaf Area Ratio 1980. June sowing:
a) 4 August harvest; b) 1 September harvest;
c) 20 October harvest.

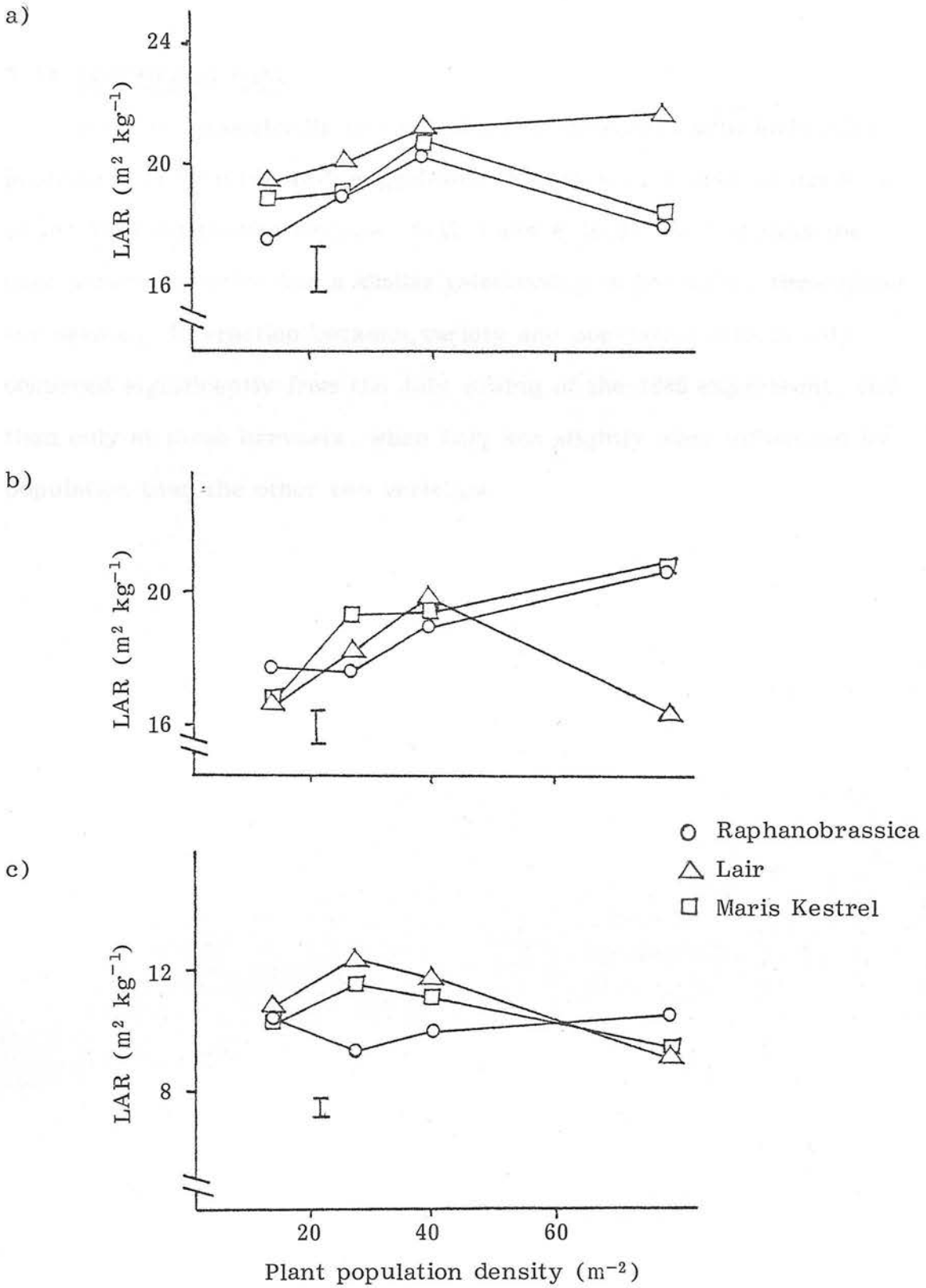


FIGURE 6.11.3: Leaf Area Ratio 1980. July sowing:
a) 1 September harvest; b) 22 September harvest;
c) 20 October harvest.

6.12 Leaf Weight Ratio

The LWR consistently and significantly decreased with increasing population in both the 1979 experiment (Figure 6.12.1) and all harvests of the 1980 experiment (Figures 6.12.2 and 6.12.3). It was thus the only parameter which had a similar relationship to population throughout the season. Interaction between variety and population effects only occurred significantly from the July sowing of the 1980 experiment, and then only at three harvests, when Lair was slightly more influenced by population than the other two varieties.

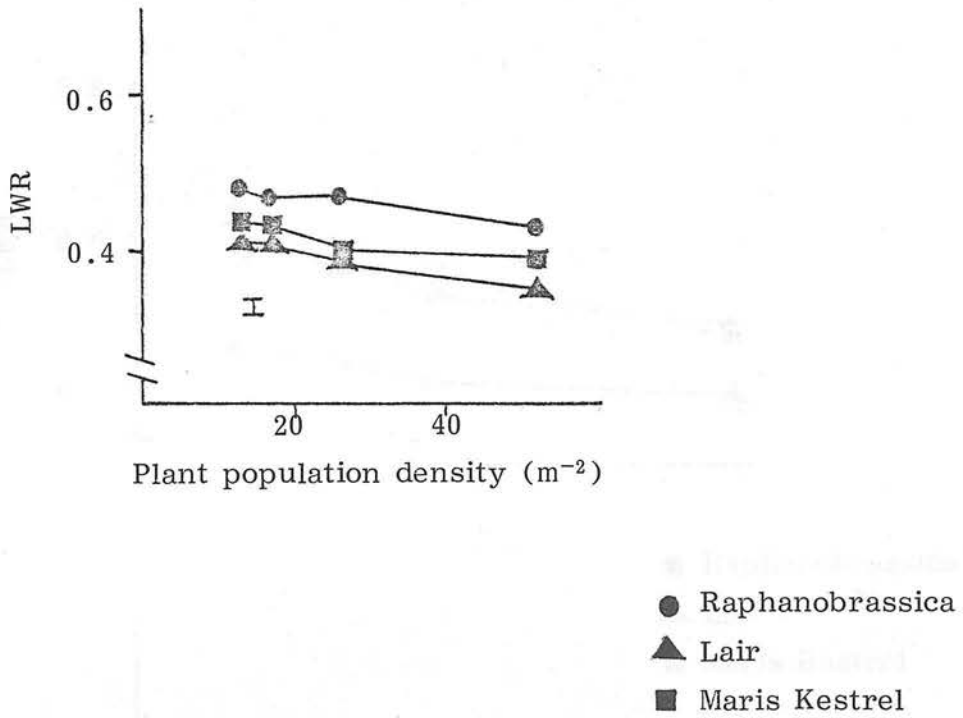


FIGURE 6.12.1: Leaf Weight Ratio 1979.

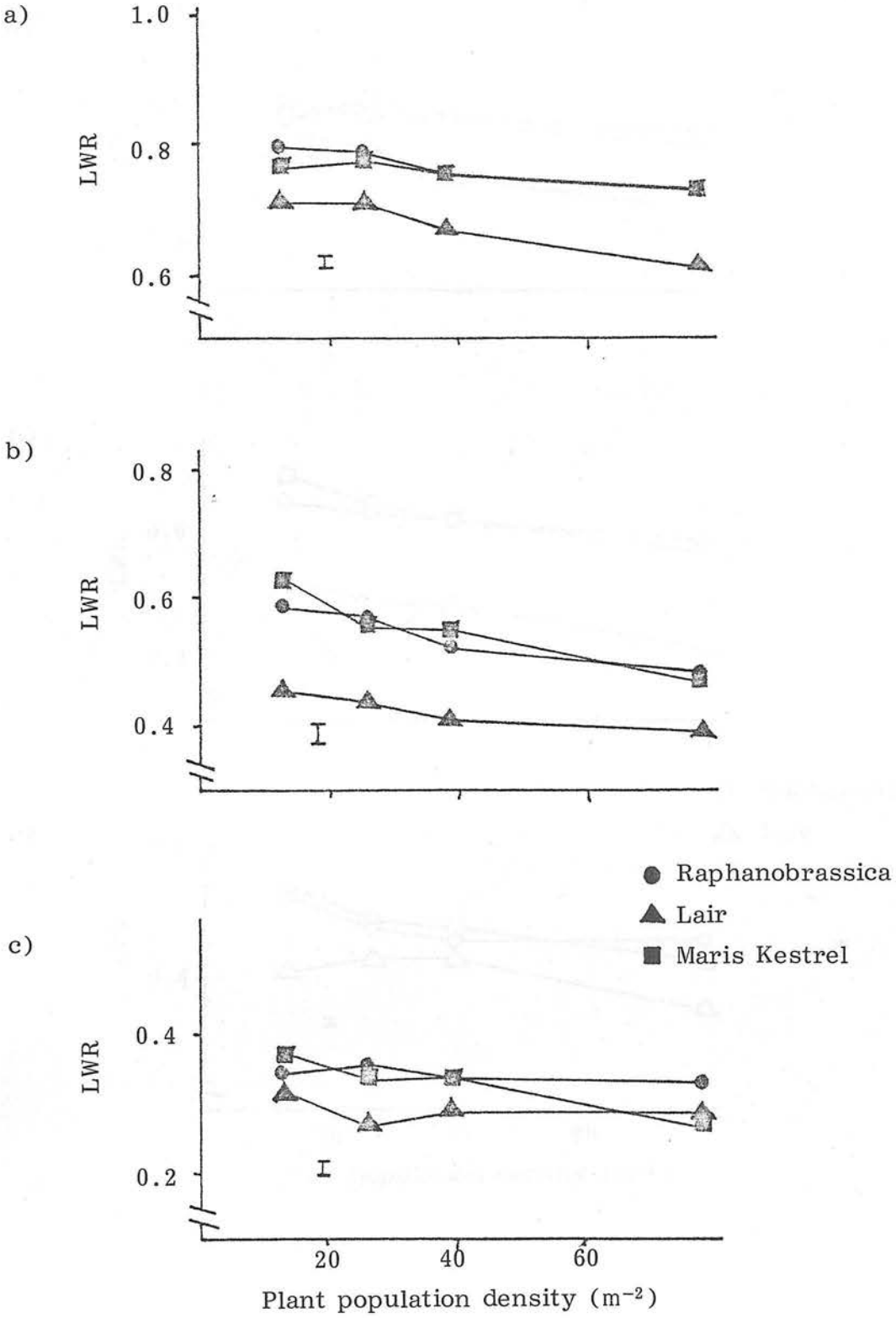


FIGURE 6.12.2: Leaf Weight Ratio 1980. June sowing:
a) 4 August harvest; b) 1 September harvest,
c) 20 October harvest.

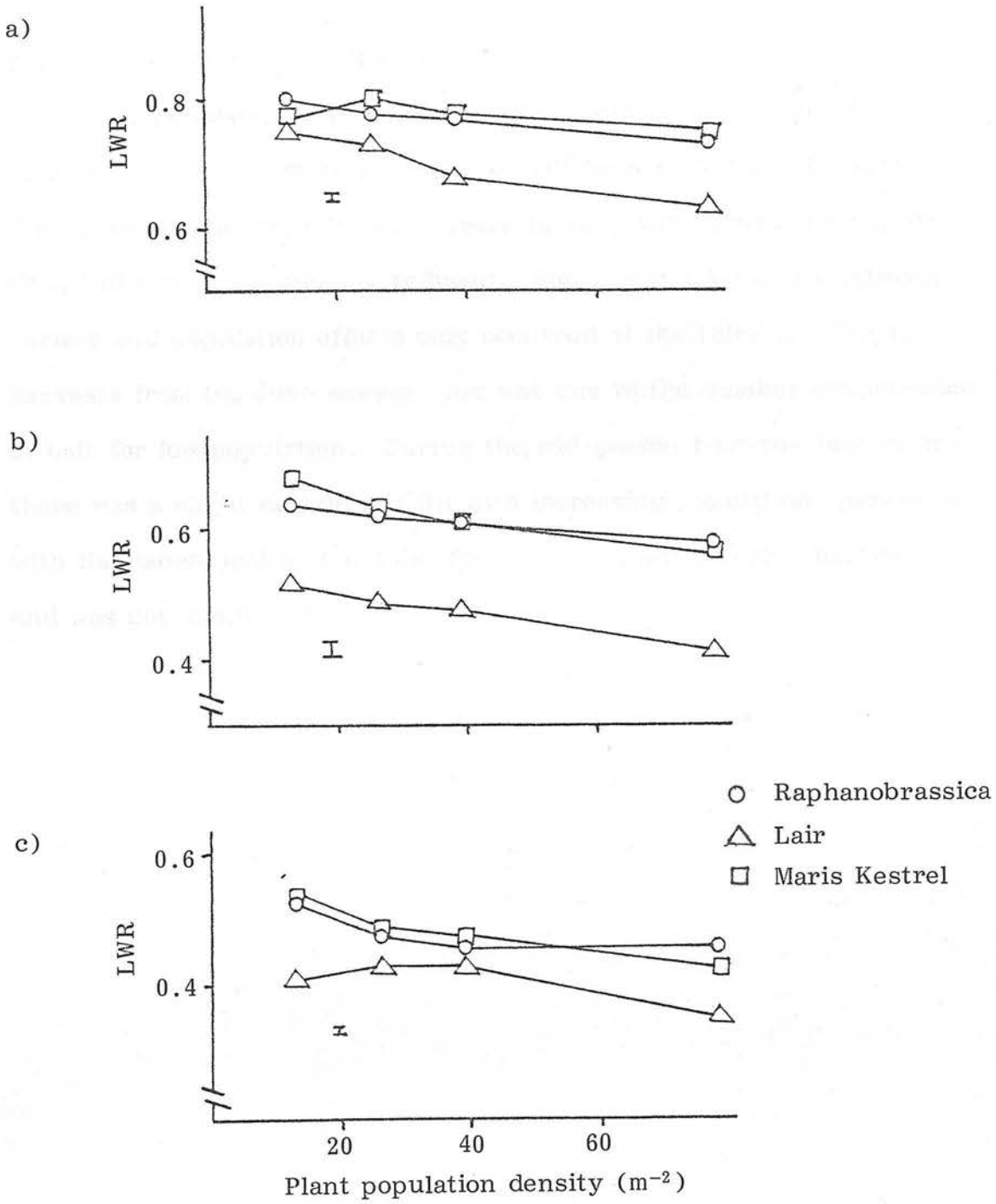


FIGURE 6.12.3: Leaf Weight Ratio. July sowing:
a) 1 September harvest; b) 22 September harvest;
c) 20 October harvest.

6.13 Crop Growth Rate (CGR)

Plant population only had a significant effect on CGR at the first three harvests from both sowings (Figures 6.13.1 and 6.13.2). The tendency was for CGR to increase linearly with increasing population, but this effect quickly reduced. Significant interaction between variety and population effects only occurred at the third and fourth harvests from the June sowing, and was due to the quicker compensation of Lair for low population. During the mid-season from the July sowing there was a slight decline in CGR with increasing population, particularly with Raphanobrassica, but this effect only appeared at this harvest, and was not significant.

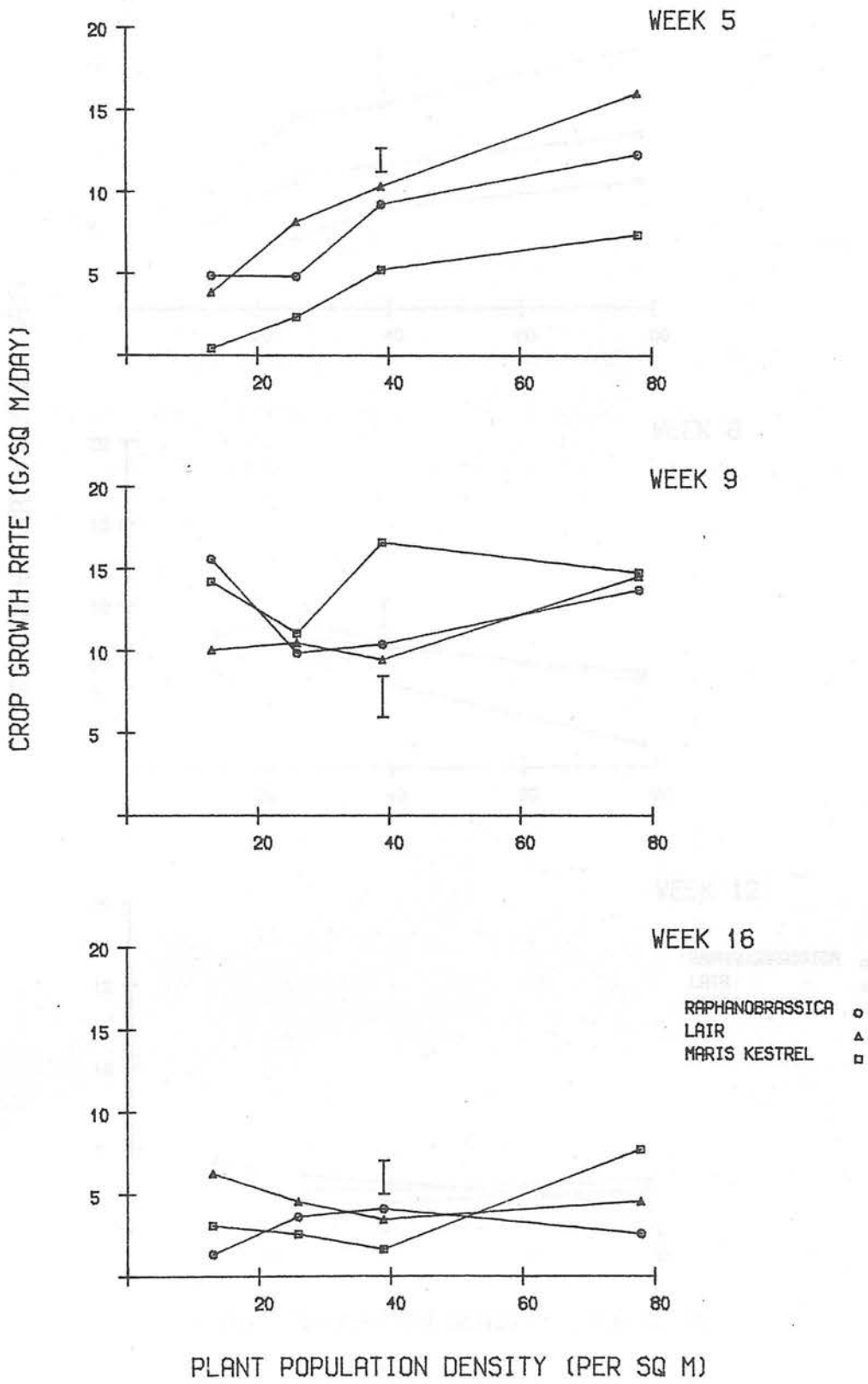


FIGURE 6.13.1: Crop Growth Rate, 1980 experiment, June sowing.

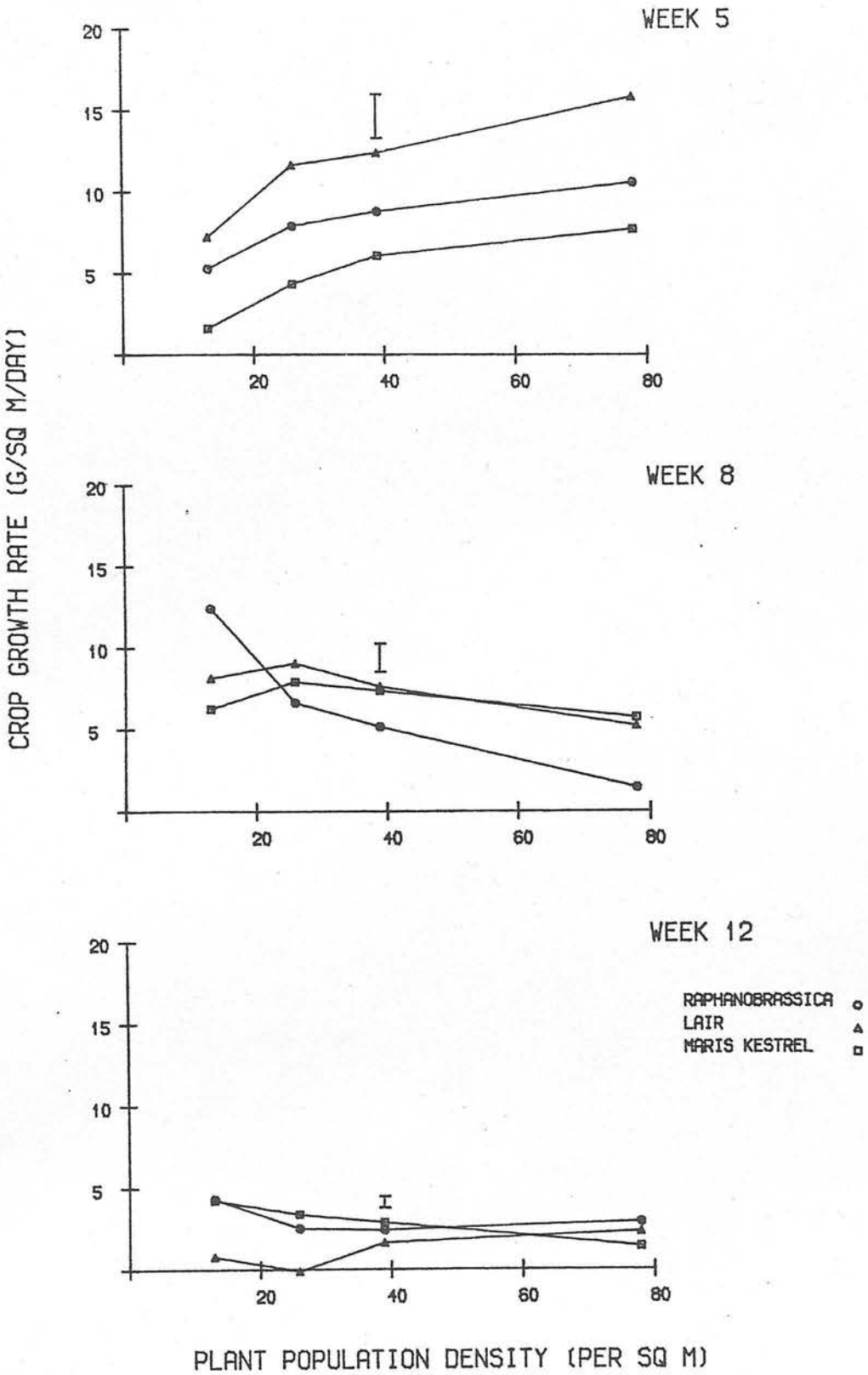


FIGURE 6.13.2: Crop Growth Rate, 1980 experiment, July sowing.

6.14 Relative Growth Rate (RGR)

RGR was significantly affected by population over the four middle harvests from a June sowing (Figure 6.14.1), but only at the second and fifth harvest from the July sowing (Figure 6.14.2). In contrast to CGR the trend was for RGR to decrease with increasing population, i.e. the greatest RGR occurred at the lowest population density. Interactive effects appeared at two harvests only, the fifth from a June sowing and the second from a July sowing. As with other parameters this was due to Lair showing less response than the other two varieties.

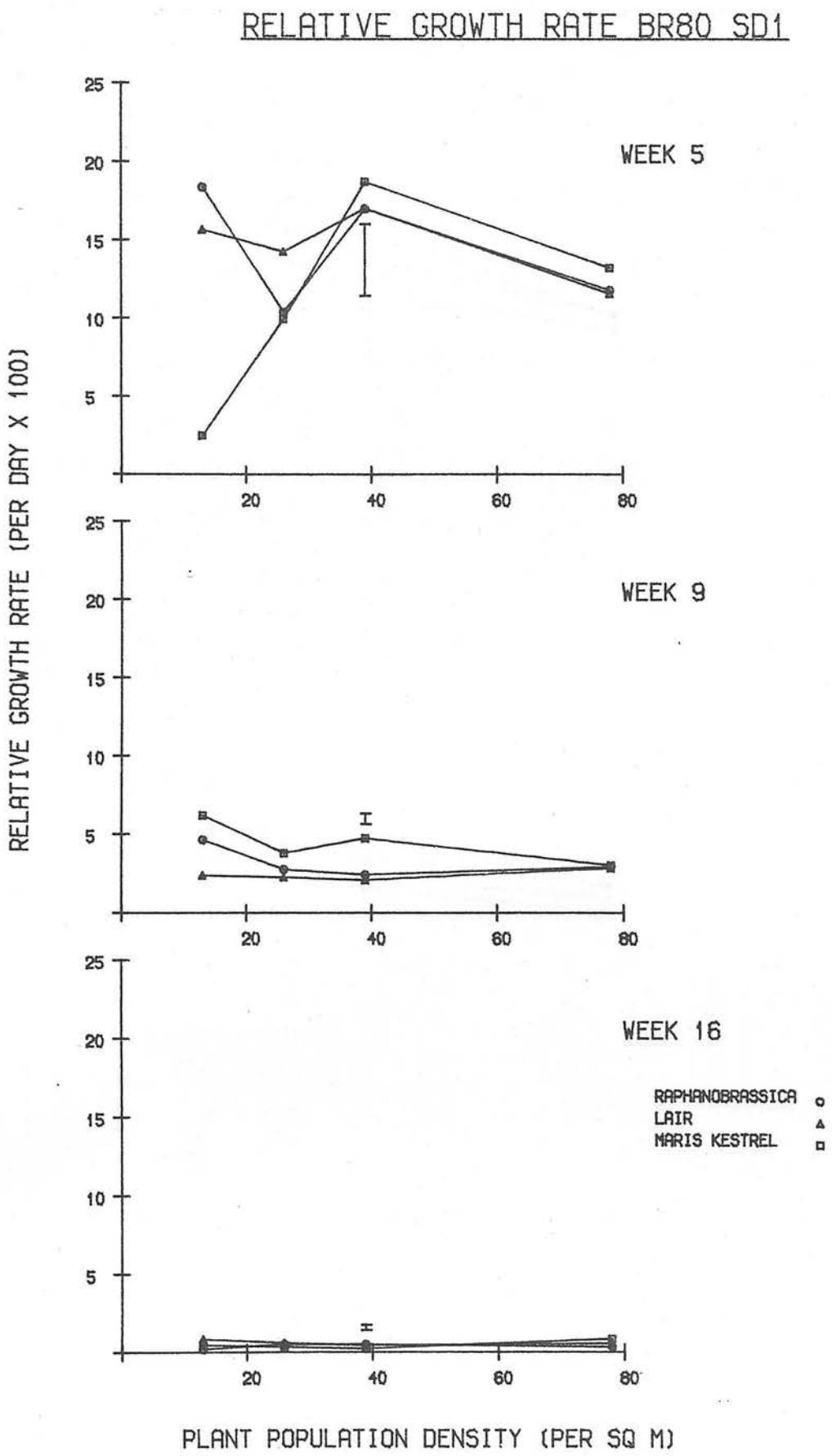


FIGURE 6.14.1: Relative Growth Rate, 1980 experiment, June sowing.

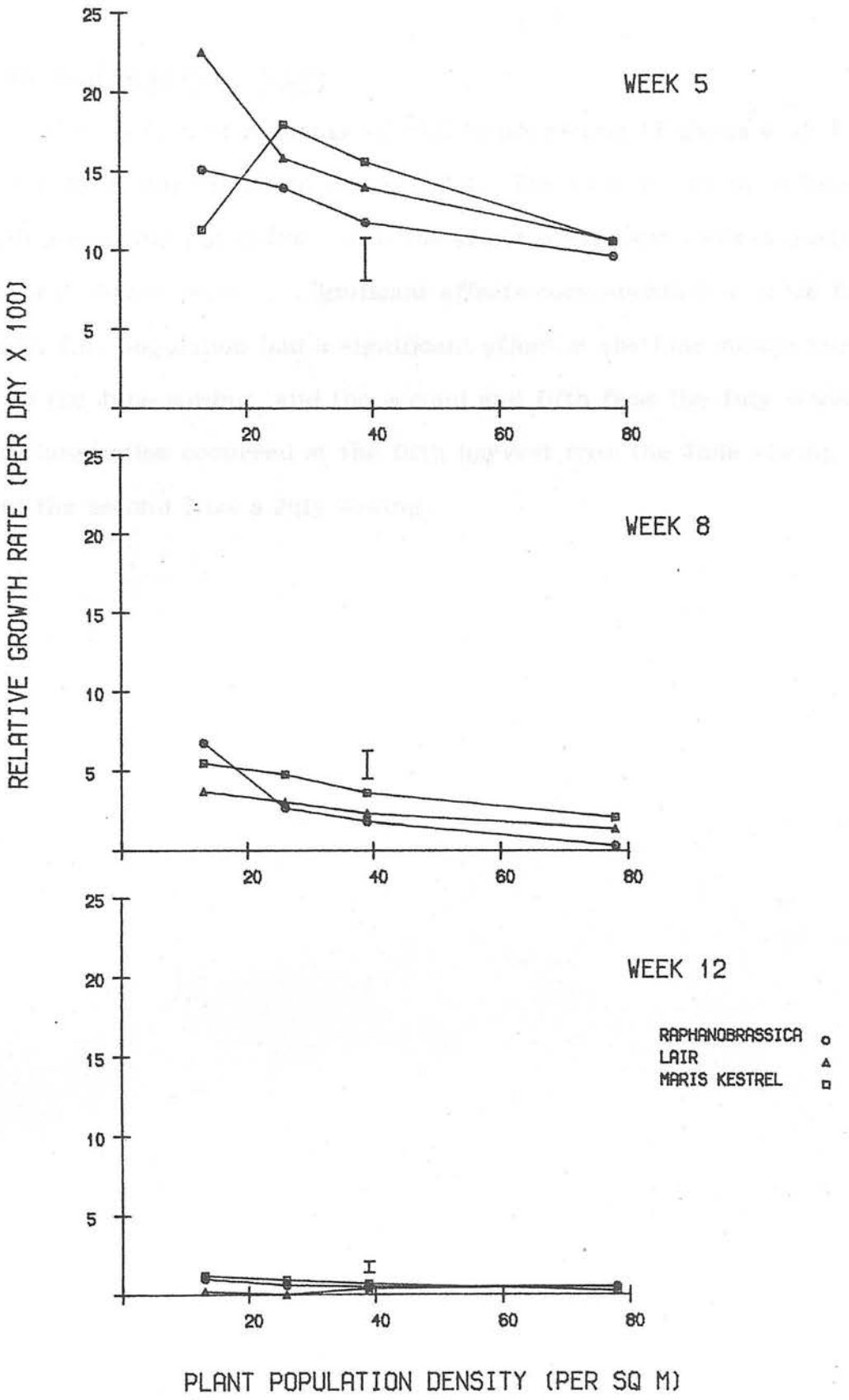


FIGURE 6.14.2: Relative Growth Rate, 1980 experiment July sowing.

6.15 Unit Leaf Rate (ULR)

The pattern of response of ULR to population (Figures 6.15.1 and 6.15.2) was similar to that of RGR. The ULR tended to decrease with increasing population, with the effect being most marked during the mid-season period. Significant effects corresponded to those for RGR, i.e. population had a significant effect at the four middle harvests from the June sowing, and the second and fifth from the July sowing, and interaction occurred at the fifth harvest from the June sowing and the second from a July sowing.

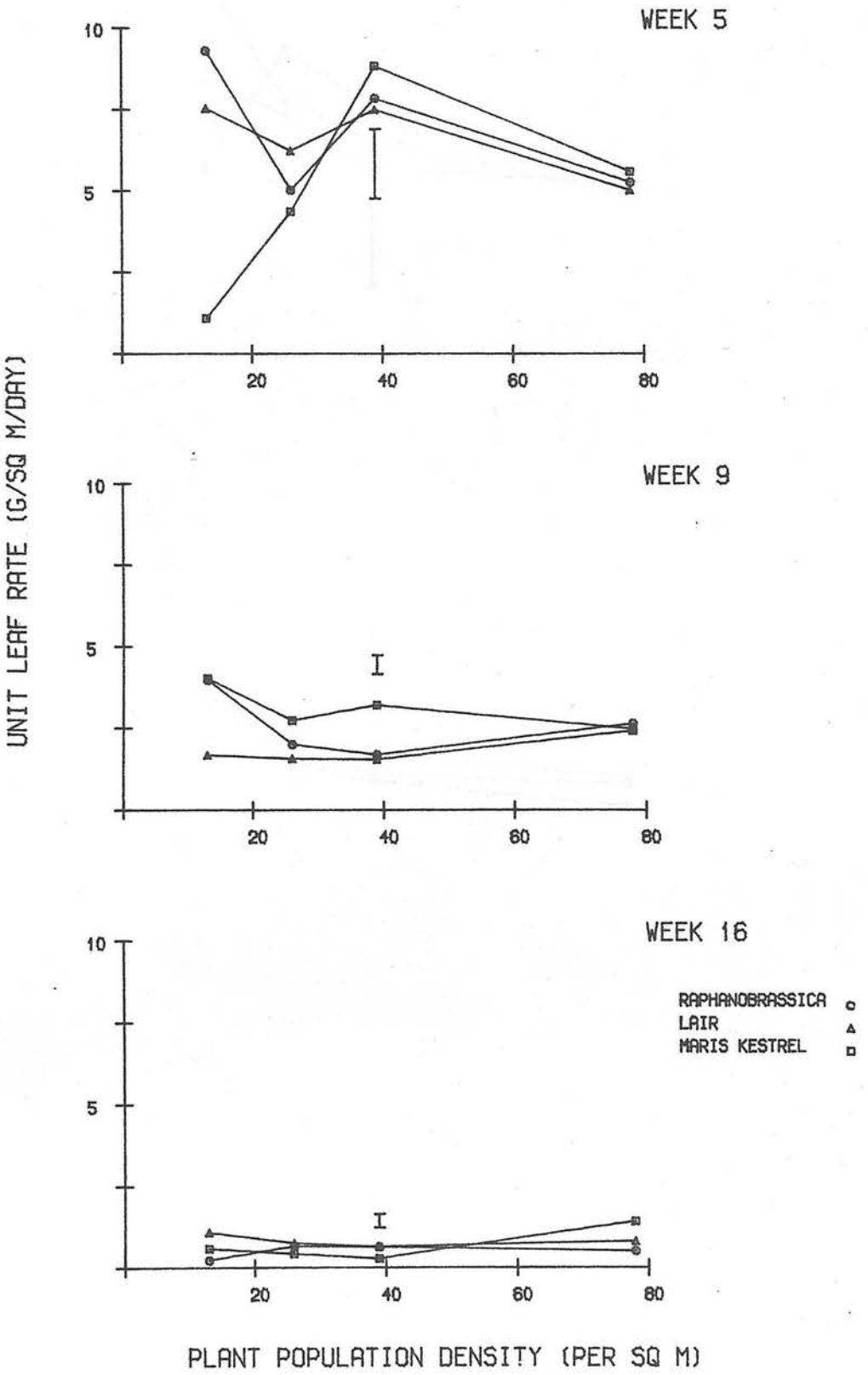


FIGURE 6.15.1: Unit Leaf Rate, 1980 experiment, June sowing.

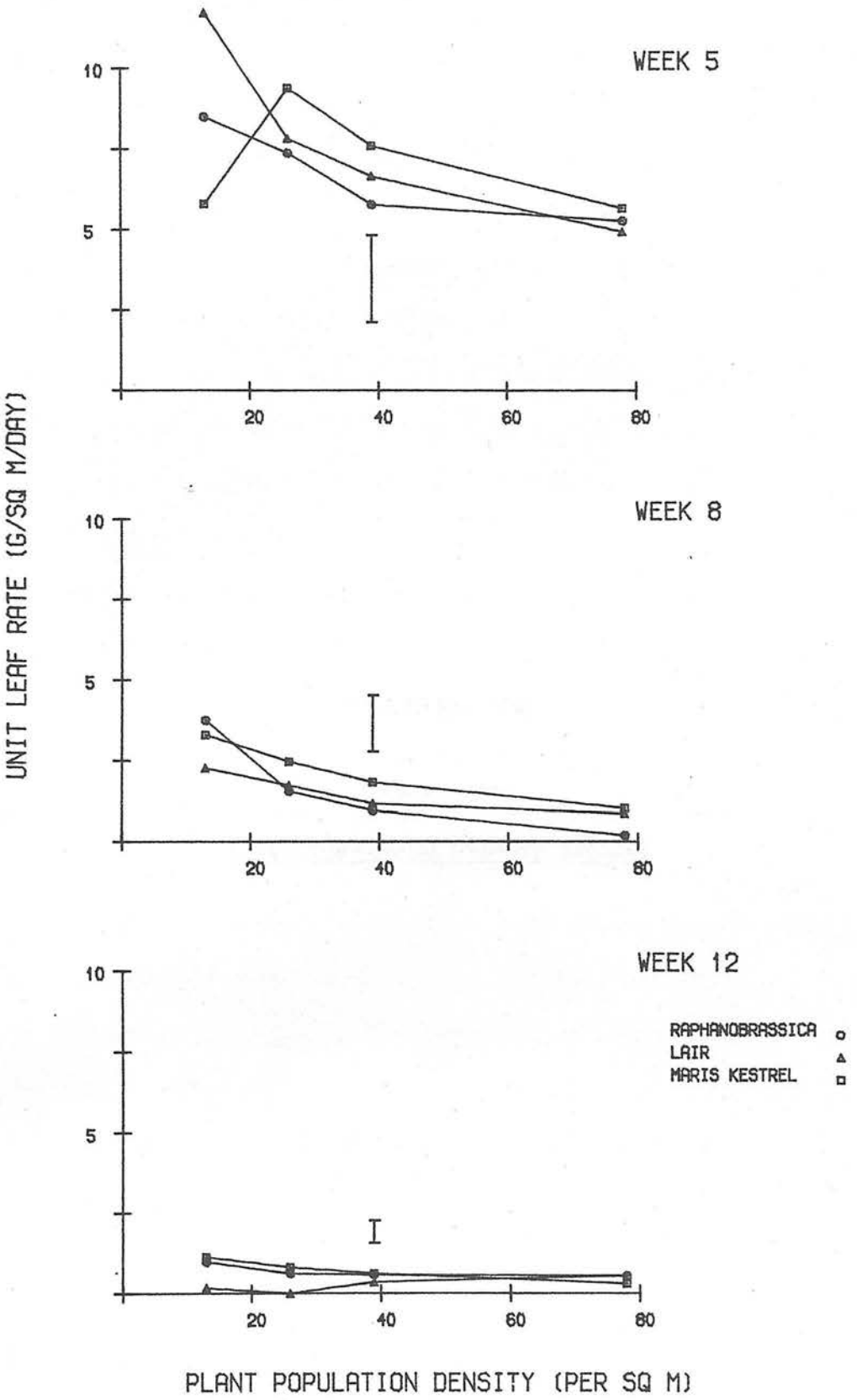


FIGURE 6.15.2: Unit Leaf Rate, 1980 experiment, July sowing.

CHAPTER VII

Discussion

Plant Population Density Effects

The general effect of plant population density on total yield was small, considering the wide range of populations employed. The maximum effect was evident early in the season, with the crops displaying an ability to compensate for reducing populations, as the season advanced, particularly in the range 40-80 $pl.m^{-2}$ (Figures 6.3.1 - 6.3.3). Lair showed both the greatest initial response to population and the greatest ability to compensate for this effect. This was in contrast to the findings of Holliday (1960), that kale had an asymptotic peak yield value at plant populations of 15 $pl.m^{-2}$, whilst with rape this occurred at much higher values of 100-150 $pl.m^{-2}$ (Holliday, 1960).

Notable differences occurred in the response of the components of yields. Early in the season the responses of leaf and petiole yields were similar to those of total yield. As the season advanced all the crops compensated for differences in population more quickly and fully, and by the end population did not have a significant effect (Figures 6.4.1 - 6.4.3 and 6.5.1 - 6.5.3). Lair again showed signs of both responding more initially to population, and compensating more quickly, particularly with petiole yield, and less so with leaf yield.

In contrast stem yield showed less initial response to population, but an increasing response as the season advanced (Figures 6.6.2 - 6.6.3). By the end of the season it was the only component of yield to be influenced by population. This is comparable to the way the crops responded to length of growing season. Variations in plant population and length of growing season both create changes in the environmental resources available to the plant. Thus, in general, it can be seen that a restriction in resources exerted the greatest influence on the yield of stem, whilst leaf and petiole yield showed an ability to compensate for such differences. Lair again showed the greatest response to population

in stem yield early in the season, particularly from the July sowing, but later in the season varietal differences disappeared.

The varying response of the partitioned yields to plant population confirms an effect noted earlier, in the 1979 sowing date x variety experiment. From the second sowing, Raphanobrassica had a much lower population, and whilst the crop recovered from initially low leaf and petiole yields, stem yield remained at a lower level throughout the season (Figures 4.3.3, 4.4.3 and 4.5.3). Holliday (1960) did not find the same effect with kale. Most of the response to plant population was shown by leaf yield (Figure 2.4.1).

The LAI of the crops showed a greater response to population early in the season than leaf yield (Figures 6.9.2 and 6.9.3), as a result of the SLA also increasing with population (Figures 6.10.2 and 6.10.3). From the June sowing, all varieties had compensated for population, in both parameters, by the sixth harvest, but some effects persisted until the end of the season from the July sowing. The difference in response of Lair, both in the initial effects of population and the subsequent speed of compensation was more marked than with the yield parameters, particularly from the June sowing. A similar ability for compensation in LAI for differences in plant population was found in kale by Watson and French (1962).

It would seem that it is leaf area which was the main influence on the response of the crops to population. Early in the season the rate of increase in leaf area of each plant within a variety was similar, resulting in the linear relationship between leaf area and population at this stage. However, as previously noted, there would seem to be a ceiling value to LAI, above which senescence of lower leaves limited further increase. The reduction in response of LAI to population as

the season advanced was thus due to a stabilisation around this peak value. The varietal differences in both initial response and speed of compensation can be ascribed to differences in the rate of increase in leaf area. Thus Lair had the greatest, and Maris Kestrel the lowest rate of increase in LAI.

It would be expected that the greater LAI of the higher population densities early in the season, when the amount of incoming radiation was greatest, would confer a growth advantage on these treatments (Appendix III). The effect on total yield was moderated, however, by the limits on leaf and petiole yield, but it was apparent in the strong influence of plant population density on stem yield.

There was a small, but significant reduction in LWR with increasing population, both in 1979 and throughout the season in 1980 (Figures 6.12.1 - 6.12.3). Thus the one consistent effect of increasing population was to slightly reduce the proportion of the crop yield in leaf. This was in consequence of both the greater initial response of stem to leaf yield, and the continued response of stem yield to population, after the crops had compensated in leaf yield.

The trends in LWR and SLA were opposite, and resulted in a small, and varying response in LAR. Early in the season, when the effect of population on SLA was greatest, LAR increased with population. The response of SLA reduced as the season advanced, and thus so did that of LAR. By the end of the season LWR was the dominant influence, and LAR was decreasing slightly with increasing population (Figures 6.11.1 - 6.11.3). As with varietal differences, there would seem to be an inherent stability in the LAR value at any one time, even over a wide range in plant population densities.

The CGR of both sowings showed a linear response to population at the early harvests, but this quickly reduced, and the effects were only significant over the first three harvests (Figures 6.13.1 and 6.13.2). Results for RGR and ULR were more variable, but both showed a decreasing trend with increasing population, which become most marked towards the middle of the season (Figures 6.14.1 - 6.14.2 and 6.15.2). This corresponded to the period of peak LAI, and represents further evidence of the effects of high LAI values on growth. Once leaf area reached a certain value mutual shading began to reduce the photosynthetic rate of lower leaves, and hence the ULR. Due to the greater LAI of the higher populations they reached this stage more quickly, and thus the downward trend in ULR developed. As LAR varied little with population, RGR followed the same trend, and hence the levelling in CGR occurred.

As with the other factors, variety and sowing date, the greater response of the early period of growth was shown. High plant populations gave an initial growth advantage, but this was balanced later by inducing a supra-optimal LAI.

CHAPTER VIII

Methods

Raphanobrassica Flowering Experiments

8.1 Introduction

In 1979 and 1980 small trials were established to investigate the pattern and control of flowering in Raphanobrassica. Fodder radish, one of the parents of Raphanobrassica, is an annual plant, and flowers from an early sowing (Banga, 1976). Raphanobrassica has inherited this tendency, as was shown by the June sowing of the 1978 field trial (Section 4.1), and in consequence it was decided to investigate this tendency more closely.

Flowering is an important factor in crop growth, as it substantially alters the growth habit. The stem elongates and becomes more fibrous, and large numbers of small, secondary leaves are produced. In addition to such changes in morphology, indications from work on fodder radish are that palatability is decreased (Section 2.5), and, from work on kale, that the level of SMCO, the kale anaemia factor, is markedly increased by flowering (Section 2.3).

Thus flowering must be seen as a detrimental effect, to be avoided. As such, it is important to establish the factors controlling the expression of flowering.

8.2 1979 Flowering Trial

The treatments used in this trial were twelve weekly sowing dates, from 1 May to 17 July, and two levels of nitrogen, 55 and 165 kg ha^{-1} N, 24 treatments in all, which with four replicates gave 96 plots. A completely randomised block design was used. Each plot consisted of 25 cm rows, 178 cm long, which were sown by hand. All sowings emerged approximately a week after planting. A week after emergence the plants were thinned to 2.5 cm spacing, although poor emergence sometimes prevented the desired population density being achieved.

Conditions were very dry during June and July, and the later sowings were watered after sowing.

Fertiliser was applied by hand immediately before sowing, at the rate of 55 kg ha^{-1} P_2O_5 and K_2O, and 55 or 165 kg ha^{-1} N. The plots were then raked smooth and level, to give a firm, even seedbed.

Flowering began in mid-July, and weekly counts of the number of flowering plants in each plot were taken. The middle three rows and 1.47 cm were considered, a plot area of 1.12 m^2. Flowering was judged to be the point when open flowers could be observed.

As the season advanced the big difference in age of some adjacent plots began to cause problems of competition. Overhanging leaves were removed, and the plots staked upright, but the later sowings were still stunted where growing beside the earliest sowings. Mature flowering plants grew to heights of over 2 m, with considerable branching occurring.

High winds in September aggravated the problem, and also made counting of the older plots difficult, due to tangling and lodging of the plants. It was thus decided to harvest the trial at the beginning of October, although the later sowings were continuing to flower, in order to obtain accurate population counts and yield data.

Harvesting was carried out on 1 and 2 October, two replicates on each day. The plants were cut at ground level, and total fresh weight and plant numbers recorded. Five plant sub-samples were taken, to determine total dry weight by drying at 80°C for 24 h.

8.3 1980 Flowering Trial

In view of the problems encountered in 1979, this trial was given a much more open design. 25 cm rows were again used, but with a plant spacing of 15 cm, achieved by hand sowing and singling. The five row plots were 5 m long, to give sufficient plant numbers, and thus, because of space limitations, fewer treatments were used. The treatments were eight weekly sowings, from 5 June to 24 July, with four replicates, giving 32 plots in all.

The seedbed was prepared as in 1979, and a fertiliser rate of 140 kg ha^{-1} N, and 70 kg ha^{-1} of P_2O_5 and K_2O was applied. Conditions at sowing were better this year, and the wider spacing allowed the plant population densities to be more accurately achieved. Emergence was in all cases approximately one week after sowing.

Similar weekly flower counts were taken from the onset of flowering, in late August. The middle three rows and 4.4 m were considered, giving a sample area of 3.35 m^2.

The problems of interference between adjacent plots and lodging were much reduced, enabling the harvesting of the trial to be delayed until 7 December. Flowering was still continuing, but it was judged that frost damage was becoming a considerable risk.

Harvesting procedure was the same as in the previous season. One row of the fourth replicate plots, which was close to a pathway, was stunted. This did not seem to affect flowering, but it was decided to exclude the fourth replicate from the yield assessment.

CHAPTER IX

Results

Effects of Flowering in Raphanobrassica

From the weekly flowering counts and the final population figures the percentage of plants in flower was calculated throughout the season for each sowing date, and each nitrogen treatment in 1979 (Figures 9.1 and 9.2). In 1979 all sowings, up to and including the eighth, sown 19 June, had showed some flowering by the time of harvest. In 1980 the first five sowings, up to 3 July sowing, had shown some flowering by harvest, but in this season harvesting was much later. Comparing the two seasons at the same date, the beginning of October, both were similar in their degree of flowering. The early June sowings produced about 35% flowering in both sowings, but whereas in 1979 the rate of flowering had levelled off, in 1980 it continued steadily through until December.

This may have been due to the lower plant populations used in 1980 (Table 9.1). The closer spacings used in 1979 led to a crowding of plants, which increased when flowering occurred. Plants which did not flower within a certain period were suppressed by competition for light from the elongating flowering plants. Thus the steady, continuous rate of flowering shown in the more open conditions in 1980 was probably a truer representation of flowering patterns.

At each successive sowing the rate at which flowering occurred became slower. This suggested that the expression of flowering as well as its initiation was being controlled by sowing date. Examination of the apical meristems of samples of the remaining vegetative plants at harvest, in 1980 found that all plants, even from the final sowing on 24 July, had fully formed floral initials.

The final flowering percentages were greater in the plots with additional nitrogen in 1979. This was probably due to the effect on plant population rather than directly on flowering, as nitrogen tended

to decrease the plant population (Table 9.1), through increasing plant competition. There was also marked variation in populations between sowing dates, due to variations in sowing conditions, which caused the changes in relative positions in flowering percentages that occurred. The treatments with higher plant populations tended to have lower flowering percentages. This was an indication that most losses were occurring in vegetative, and hence smaller, plants. Due to the lower populations used in 1980 there was less variation between sowing dates.

The final dry matter yields are shown in Figures 9.4 and 9.5. In both seasons the trend was for yield to be reduced by later sowings. Yields were particularly low from the last sowing in 1979, due to competition from adjacent plots. Yield from comparable sowings was lower in 1979 than in 1980, due to the earlier harvest. Sowing earlier than early June did not further increase final yield. The nitrogen treated plots in general produced a higher yield. Flowering did not affect final yields to any extent, but did have an effect on dry matter content (Figures 9.5 and 9.6).

In 1979 the first four sowings, with over 20% flowering had similar, high dry matter contents, after which the content reduced with later sowing date. In contrast, in 1980, the non-flowering sowings all had a similar, low dry matter content, whilst the earlier sowings reduced in dry matter content with later sowing date.

Due to the later harvest the dry matter contents in 1980 were at a higher level than in 1979. The additional nitrogen treatment tended to decrease dry matter content slightly in 1979. In both seasons flowering plants tended to have a greater dry matter content, although it was difficult to separate this from the age effect also occurring.

TABLE 9.1: Final plant populations (m^{-2}) in the Raphanobrassica flowering experiments, from counts taken at harvest, on 1 and 2 October in 1979 and 7 December 1980.

1979

	Sowing date:											
	1/5	8/5	15/5	22/5	29/5	5/6	12/6	19/6	26/6	3/7	10/7	17/7
+N	60.4	74.8	57.1	52.2	61.4	74.5	66.3	61.4	62.3	69.9	77.8	68.9
-N	70.5	83.7	76.4	60.4	94.8	91.9	81.4	77.8	64.3	90.2	87.6	76.4

SED = 8.34

1980

Sowing date:							
5/6	12/6	19/6	26/6	3/7	10/7	17/7	24/7
17.3	15.5	17.5	17.7	19.1	21.4	18.1	20.0

SED = 1.58

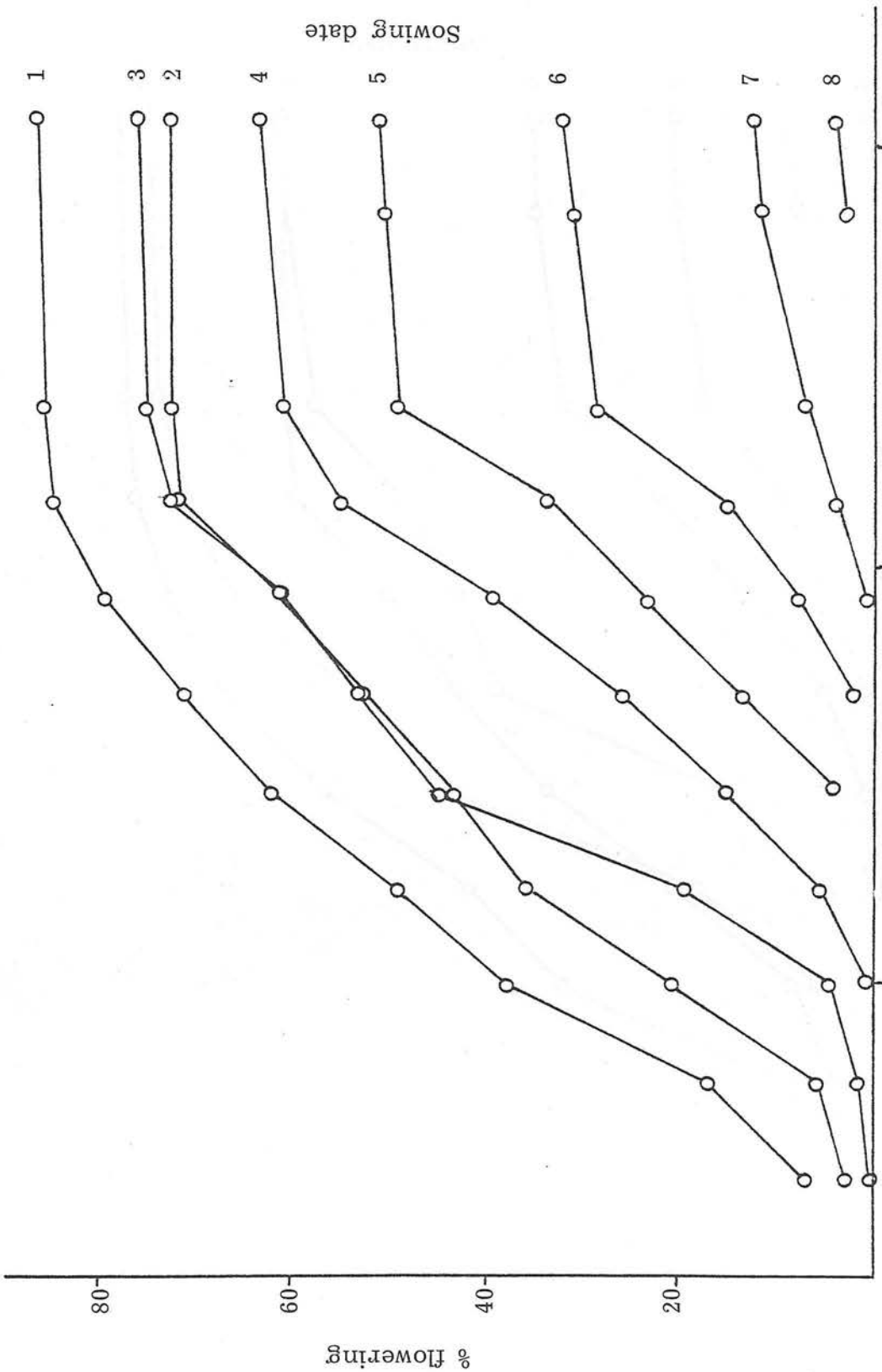


FIGURE 9.1: Percentage of Raphanobrassica plants in flower throughout season. High nitrogen treatment of 1979 flowering experiment.

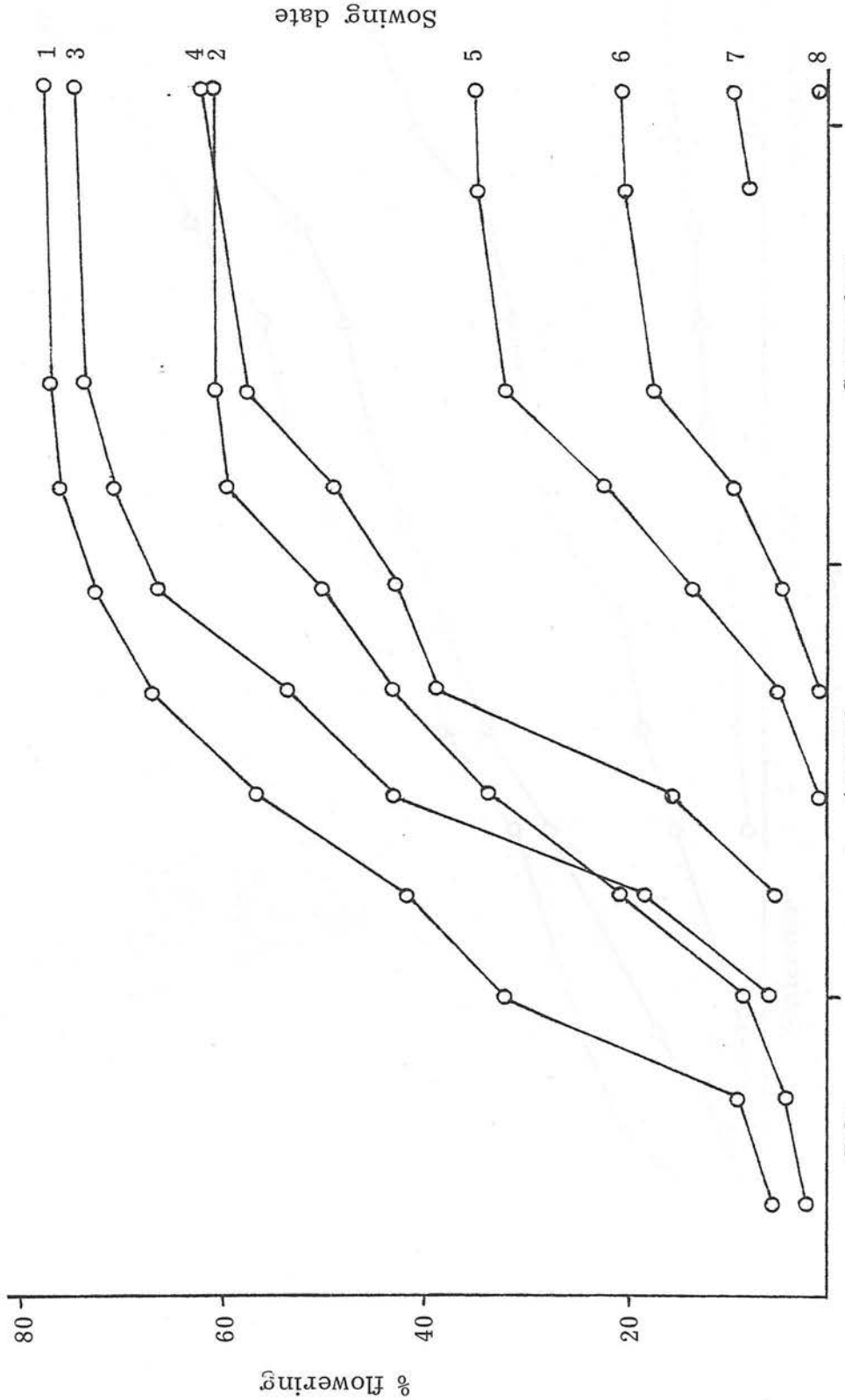


FIGURE 9.2: Percentage of Raphanobrassica plants in flower throughout season. Low nitrogen treatment of 1979 flowering experiment.

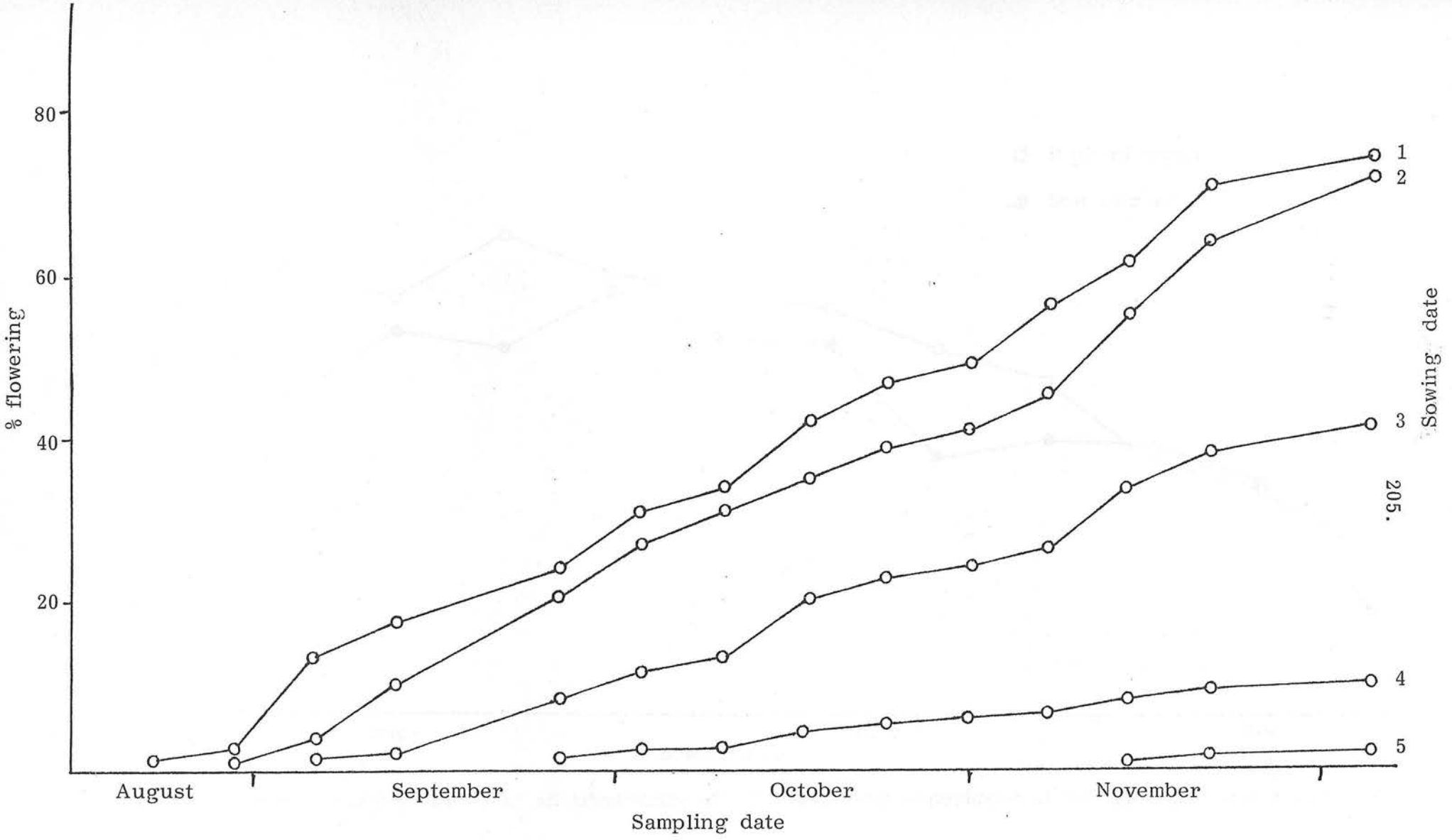


FIGURE 9.3: Percentage of Raphanobrassica plants in flower throughout season. 1980 flowering experiment.

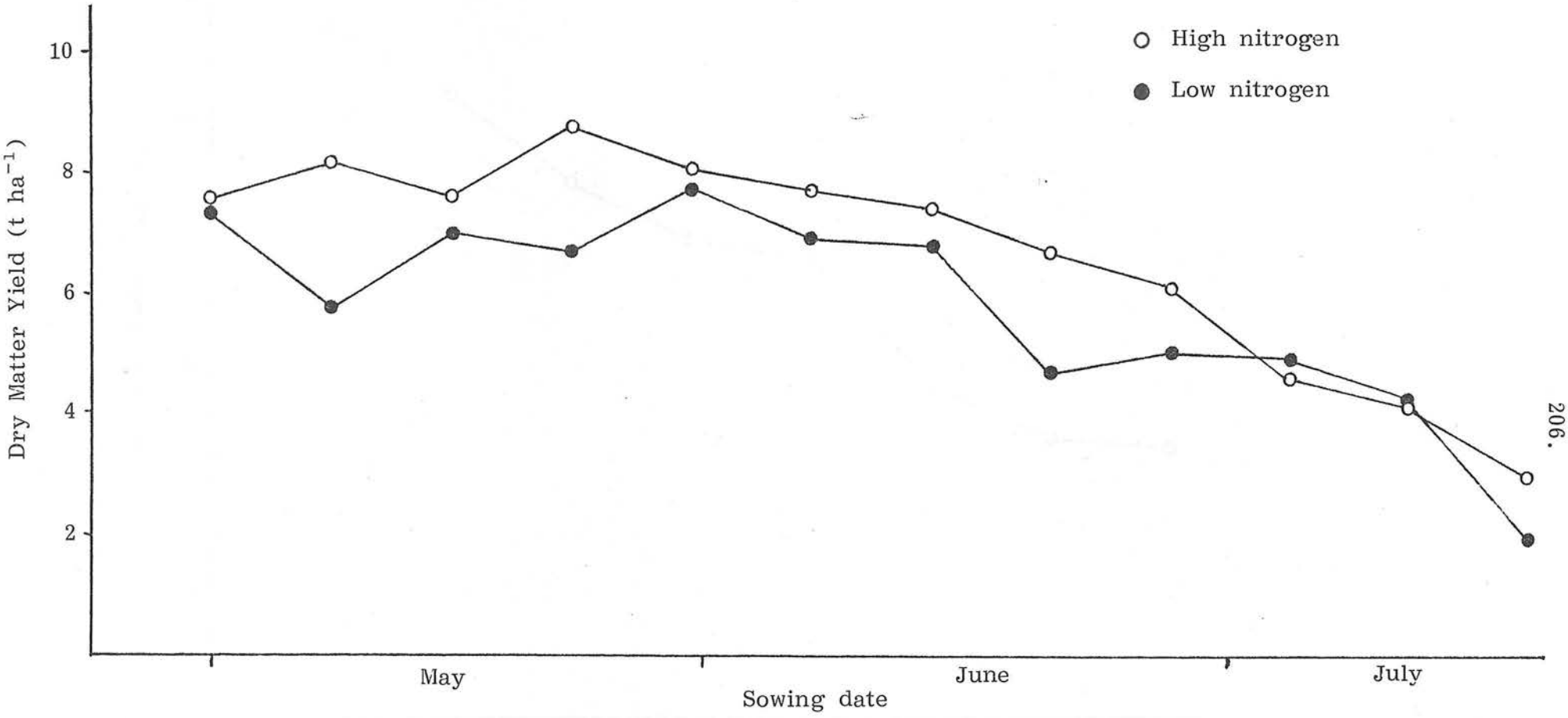


FIGURE 9.4: Dry Matter Yield (t ha^{-1}) of all treatments of 1979 flowering experiment at harvest on 1 and 2 October.

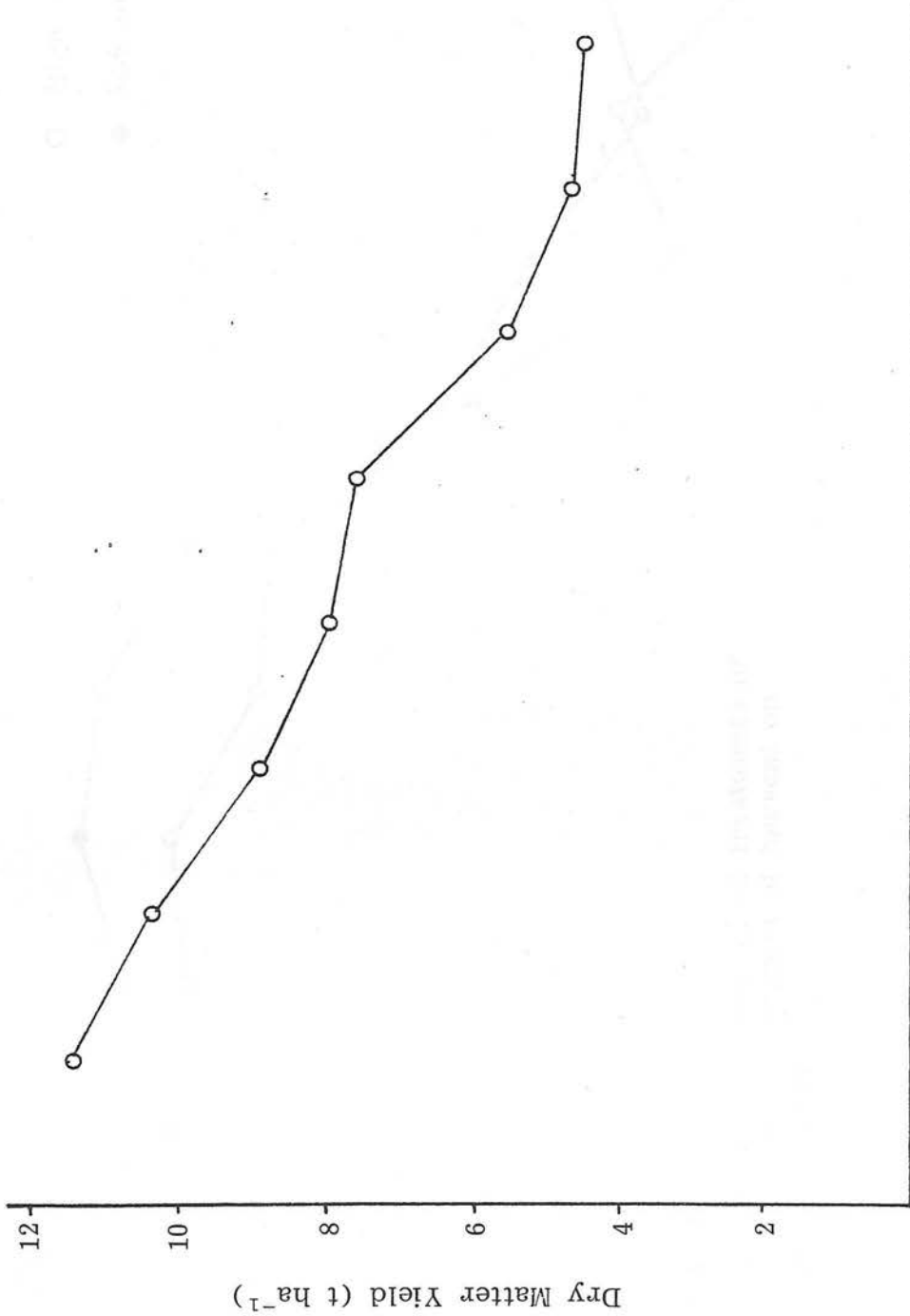


FIGURE 9.5: Dry Matter Yield (t ha^{-1}) of all treatments of 1980 flowering experiment at harvest on 7 December.

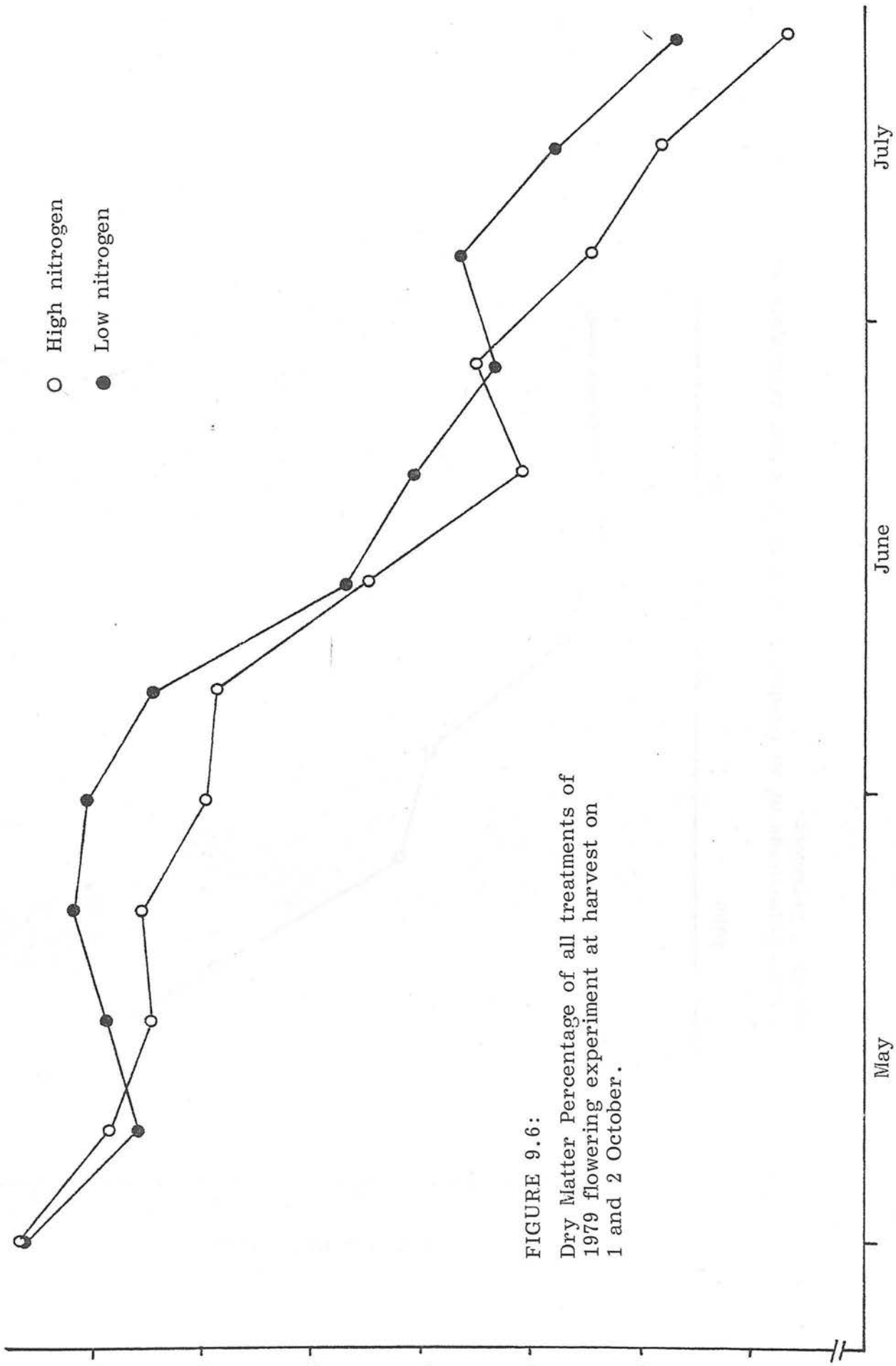


FIGURE 9.6:
Dry Matter Percentage of all treatments of 1979 flowering experiment at harvest on 1 and 2 October.

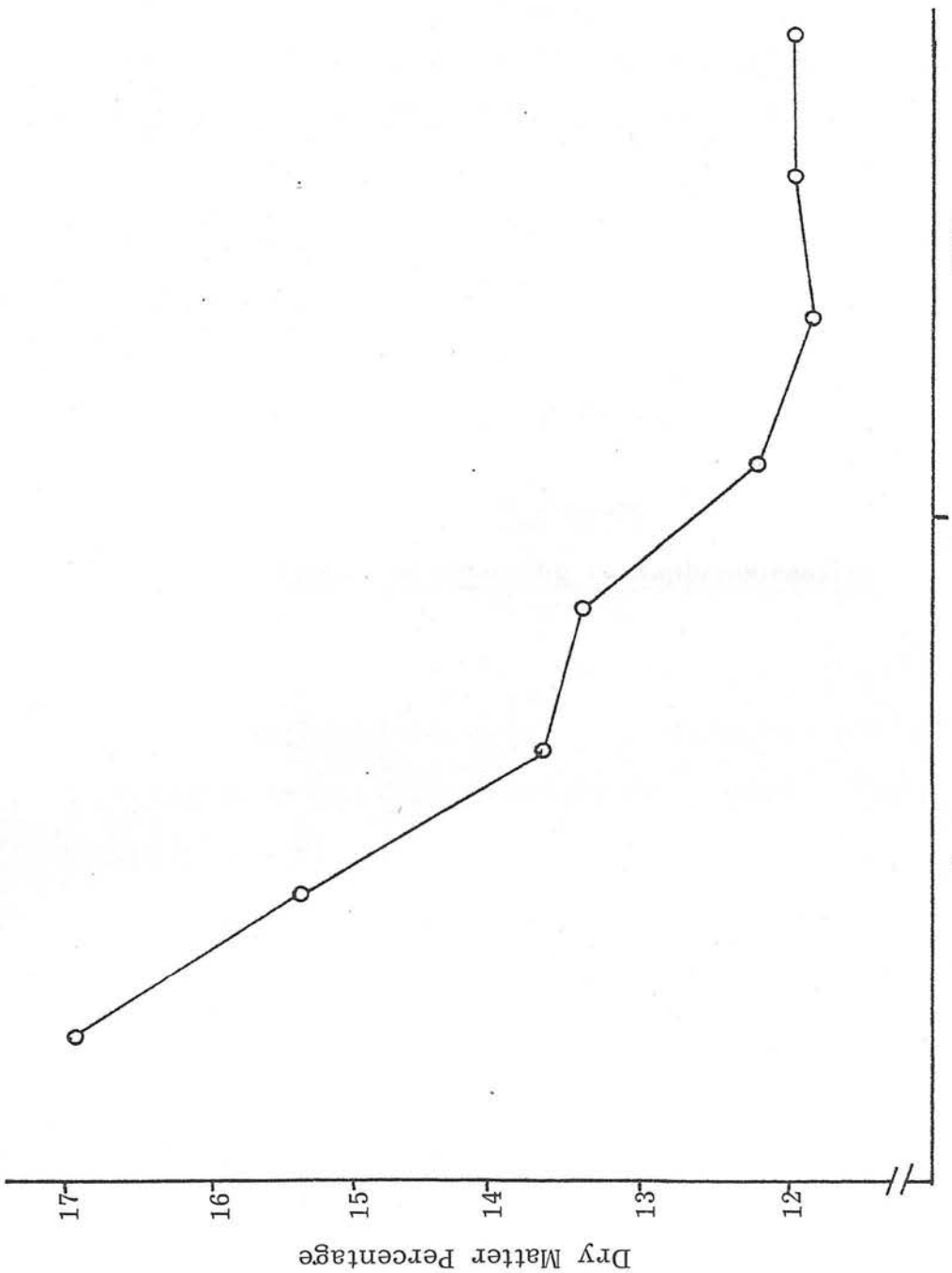


FIGURE 9.7: Dry Matter Percentage of all treatments of 1980 flowering experiment at harvest on 7 December.

CHAPTER X

Discussion

Effects of Flowering in Raphanobrassica

A clear sowing date effect on the flowering of Raphanobrassica was shown by both the flowering experiments in 1979 and 1980 (Figures 9.1 - 9.3) and also the sowing date x variety experiments in 1978 and 1980 (Tables 4.1.1 and 4.1.2). The pattern of response, with a decline in flowering from early July sowings onwards suggests a quantitative response to long daylength. However, no treatment produced 100% flowering, whereas this was achieved by overwintered plants grown for seed by the National Seed Development Organisation, Cambridge (Dr. I.H. McNaughton, personal communication). This indicates that long daylength was not an obligatory requirement for flowering, and that cold treatment could induce full flowering. A consideration of the background of the hybrid indicates that both may indeed be present within the crop. A wide variety of flowering responses has been found in the brassica group, with plants showing various degrees of sensitivity to both temperature and photoperiod, or a combination of the two.

A strain of annual turnip rape, *Brassica campestris* L. ssp. *oleifera*, called Ceres, has been shown to be a quantitative long-day plant, with no critical daylength, but showing more extensive and earlier flowering the longer the daylength (Friend, 1969). This response was obtained with just one photoperiod, with no obligate cold requirement. At the other extreme brussel sprouts, *B. oleracea*, var. *gemmifera*, has an obligate cold requirement and no photoperiodic requirement for flowering (Stockes and Verkerk, 1950). Cabbage, *B. oleracea*, var. *capitata*, also has an obligate cold requirement, but thereafter daylength has been shown to have an effect, with long days promoting flowering (Heide, 1970).

No detailed work has been done on the kales, *B. oleracea*, var. *acephala* and *fruiticosa*, but it is known that they have a similar cold

requirement to brussel sprouts and cabbage (Lynch, 1977). There has likewise been no detailed study of the flowering response of the other parent of Raphanobrassica, fodder radish, *Raphanus sativus*, var. *oleifera*. Work on the culinary radish, *R. sativus*, var. *radicula* indicates that a dual response exists within the species (Suge and Rappaport, 1968). Cold treatment induced full flowering, in short or long days, but with no cold treatment a daylength of 16 hours would induce 60% flowering. A similar photoperiod response was indicated by experiments in the field with fodder radish (Section 2.3.6), but with considerable variation between varieties.

The line of Raphanobrassica used in these flowering experiments had a parentage of thousand-head kale and bolting resistant fodder radish varieties (Dr. I.H. McNaughton, personal communication). It would seem to exhibit a flowering response similar to its radish parent, in that cold treatment induced full flowering, whilst in the absence of this a partial response to long daylength was shown. The observation that all sowings had fully formed floral initials when examined in 1980 was thus due to this examination taking place in early December, when temperatures were low enough to have induced flowering (Appendix III). Effective vernalisation of radish has been shown by exposure to 5°C for 20 days (Suge and Rappaport, 1968). A similar optimum of 4°C was shown in cabbage (Heide, 1970), where 28 days were required, and up to 10°C was partially effective.

The pattern of flowering in the two flowering experiments (Figures 9.1 - 9.3) was a steady increase in the number of flowering plants, which persisted for the whole of the season in 1980. This rate decreased with advancing sowing date, which suggests that this factor was not simply influencing the degree of flowering initiation but also the timing

of the expression of flowering. In an experiment on spring rape, *Brassica napus*, ssp. *oleifera*, in Australia, it was found that floral initiation was controlled by cold treatment. In contrast, the duration of the stem elongation phase, from initiation to anthesis, was insensitive to cold treatment, but highly responsive to variation in photoperiod and temperature after initiation (Thurling *et al.*, 1977). It was concluded that the mechanism regulating the timing of flowering was independent of floral initiation. A further indication of this was given by an experiment on culinary radish (Suge and Rappaport, 1968). It was found that treatment with gibberellic acid had little effect on floral initiation but reduced the number of days to anthesis.

It can thus be hypothesised that the difference in flowering rates with sowing date shown by Raphanobrassica was due to a combination of a photoperiodic effect on the number of plants initiated, followed by a further, quantitative effect of photoperiod and temperature on the time taken from initiation to the expression of flowering. For there to be such a long sustained period of flowering there must be a substantial amount of variation within the crop in the time taken to flower. However, this could be accounted for by the varied background of the crop and the complex nature of the flowering mechanisms, indicating a wide genetic control.

Total dry matter yield showed the same linear relationship with length of growing season in the 1980 flowering experiment (Figure 9.5) as observed in the main field trials (Figure 4.2.5). The flowering of the earlier sowings did not seem to have a significant effect. However, in the 1979 flowering experiment this linear relationship was less evident (Figure 9.4). From sowings in June onwards there was some evidence of a linear decline, in particular from the nitrogen treated plots.

Variation was greater in the 1979 experiment due to differences in plant population between sowings (Table 9.1) and also competition between adjacent plots. From sowings from early May to early June little change in final yields was shown. The earlier sowings had a high proportion of tall flowering plants, which as they matured tended to lose their lower leaves and produce an increasingly tall and lignified stem. This had the effect of reducing their growth rate and also suppressing the growth of their much shorter vegetative neighbours. It is thus possible that in the absence of flowering final yields could have been further improved by sowings earlier than June. Experiments with kale, however, suggest a more variable response to May sowings (Section 2.3.1).

As in the sowing date trials (Figures 4.7.1 - 4.7.3) there was a general increase in DMC with sowings earlier than July (Figures 9.6 and 9.7). The lack of response to later sowings of final DMC noted in the sowing date trials was clearly shown by the 1980 flowering experiment (Figure 9.7). The higher levels of DMC in the 1980 experiment compared to 1979 were due to the later harvest in 1980. The particularly high value of 17% DMC of the first sowing in 1980 was due to the high proportion of mature flowering plants with tall lignified stems.

CHAPTER XI

General Discussion and Conclusions

The most notable point to arise from these series of experiments was the basic similarity of the overall growth patterns of the crops, regardless of the genetics and cultural variation. Final total yield was closely linked to the amount of received radiation, and this allowed the calculation of a generalised linear relationship between length of growing season and total yield, which could be applied to all three varieties in all three seasons. For every additional 11 days of growing season another 1 t ha^{-1} dry matter yield was produced. This relationship can only be applied within the range used in the experiments, 95 - 160 days, further extrapolation would not be justified. It also applies to final total yields, at mid-November harvest in East Scotland. However, in spite of these limitations, the relationship illustrates the importance of length of growing season as a determining factor of yield potential. In comparison variation in plant population density had relatively small effects.

Consideration of the components of final yield, revealed a further aspect of this generalised relationship. Most of the response to length of growing season was found to be in the stem yield. The same found to be true of the response to plant population density. Varietal differences occurred here, with Raphanobrassica tending to have the greatest final leaf and petiole yield and the lowest stem yield, whilst Lair had the lowest leaf and petiole yield and the greatest stem yield. These effects on yield partitioning have important implications for crop usage. The ultimate value of any crop to the grower is not the overall yield, but the yield and quality of the economically useful part of the crop. With leafy forage crops the economically important aspect of the yield is the feeding value of the aerial parts of the plant.

This is influenced by yield, digestibility and the degree of utilisation of the crop by grazing animals.

Leaf is generally considered to be the most nutritious part of the crop (Dent, 1963 a,b), and so if nutritive value was the only consideration Raphanobrassica would seem to be the superior crop. Also, length of growing season and population, with influence mainly on stem yield, have less effect on the digestible yield than on total yield. However, the degree of utilisation is also a factor, and is influenced by crop morphology. There have been many observations of the preferential selection of leaf by grazing animals (Greenall, 1958; Johnston, 1961; Keane, 1979; Paterson *et al.*, 1977; Furber, 1978), suggesting that this is the most palatable part of the crop. However, high levels of wastage are typically encountered in grazing, and it has been noted that rape and kale, with higher canopies, were less prone to wastage through soiling of leaves than root crops with a lower canopy (Bastiman, 1977). Thus a crop with a high proportion of stem, whilst having a lower digestible yield than a more leafy crop, may have a greater feeding value through promoting less wastage.

The effects of sowing date, plant population and variety on the morphology of the crop are shown in Plate 1. Early sowing and high population increased stem yield and hence height of the canopy. The lower stem proportion and thus lower habit of Raphanobrassica can also be seen. This could explain the poorer performance of lambs on Raphanobrassica compared to rape in grazing trials (McNaughton, 1979, 1981).

Palatability may also be a factor. As was shown by the accidental introduction of sheep onto the 1980 experiment, animals display a strong preference for rape, in particular young rape plants, to either kale or

Raphanobrassica (Section 3.6.4). A few kale leaves were sampled, but the only interest shown in Raphanobrassica was as shelter. It seems likely that such preferences would affect intake rates on single crops. More work is required to establish the effects of these various factors on utilisation rates.

Variety trials tend to simply consider relative total dry matter or digestible yield. Apart from the limited usefulness of such yield data in isolation, the fact that in general only one sowing date and one harvest date is employed is a further limiting factor, as these experiments demonstrate. The differences in total yield towards the end of the season were admittedly low, but such small differences are nonetheless often the basis for the selection or rejection of a certain variety. The results show how such comparisons can be influenced by sowing and harvest date. Lair had a faster early growth rate, whereas kale had a lower initial growth rate, but was more persistant in growth towards the end of the season. Thus late sowings and early harvests favour Lair, whilst earlier sowings and late harvests give Maris Kestrel the more favourable comparison.

Another sowing date effect was the expression of flowering in Raphanobrassica, which occurred to some extent in sowings before the end of June. It had the effect of increasing the proportion of stem, and also the dry matter content. Work on kale also suggests that the level of the kale anaemia factor, SMCO, is increased during flowering (Whittle *et al.*, 1976), and work on radish suggests that flowering plants are less acceptable to grazing animals (Boyd and Dickson, 1966; Furber, 1978). Thus flowering must be regarded as an undesirable effect, placing a constraint on early sowings of Raphanobrassica.

All these considerations illustrate the difficulties that confront the breeder in trying to select an improved variety. Not only are there problems in the assessment of the potential of a variety, but efforts to improve it may result in unforeseen effects which reduce its value. The results indicate that it is LAI that is the main determinant of crop growth, with a ceiling LAI value limiting further leaf and petiole growth. Work by Watson (1956), comparing kale and sugar beet, and Watson and Witts (1959), comparing wild and cultivated beets, suggests that optimum LAI is higher in crops with a more erect canopy. This is due to a more efficient use of light through a better penetration and hence distribution throughout the canopy.

However, no great differences were detected in the maximum LAI of the three varieties considered here (7.0 - 7.5 from the June sowing and 4.5 - 5.5 from the July sowing in 1980), in spite of certain differences in canopy morphology. Raphanobrassica had a more erect canopy, with a larger number of more fibriallated leaves, whilst Maris Kestrel had a more planar canopy, with fewer but larger, more continuous leaves, and Lair had an intermediate pattern (Plate 1). This suggests that attempts to increase the optimal LAI through changes in canopy structure would meet with a limited response. In addition the more efficient, erect rosette pattern of growth would meet with the problems of utilisation mentioned earlier.

Raphanobrassica produced a superior leaf yield, by virtue of having a lower SLA . However, this higher leaf yield was at the expense of stem. Ideally the fast initial growth rate and higher stem yield of Lair would be combined with the higher leaf yield of Raphanobrassica. The critical period for the establishment of the initial yield advantage of Lair was the first four weeks of growth, and

the determining factors have not been identified. Measurements at the first harvest indicate a similarity in growth parameters at this stage. Thus the notably greater SLA of Lair did not develop until later in the season, and thus would not seem to be a crucial factor in initial growth.

The significance of the earliest part of growth is also an important finding with regard to the cultural requirements of the crops. It indicates that seed-bed conditions and conditions during the first month of growth are the most critical for the achievement of early maximum yields. Nonetheless the magnitude of final total yields depends on length of growing season rather than environmental conditions, at least within the range encountered in these experiments. The ability of the crops to compensate in overall yield for variations in conditions, sowing date and plant population density indicate the degree of flexibility possible when growing the crop. However, the effects of these factors on crop morphology should always be considered as an additional factor.

Work on the further improvement of Raphanobrassica is now at a low level, and the prospects for a commercial introduction seem distant. Its high yield potential, particularly of leaf, has been demonstrated, which along with its clubroot resistance are attractive features. However, the problems of flowering and palatability and seed production still need to be resolved.

Work on kale variety improvement is also now at a low level in the UK, and Maris Kestrel remains one of the standard commercial varieties. It shows as good a yield potential as the other two crops, given a sufficiently long growth season, and its persistence of growth late in the season and frost hardiness make it the best choice for late autumn grazing.

Selection for improved varieties of rape continues, and Lair has become outclassed by more recent introductions. The high and early yielding characteristics makes rape the best choice for early harvests or late sowing. The lower leaf yield and lack of clubroot resistance offers potential for further improvement of the crop.

(a)

(b)

PLATE 1: Plants from the 1980 experiment at the final harvest in November.

(a) 78 $pl.m^{-2}$ (b) 13 $pl.m^{-2}$

Varieties (L - R) Raphanobrassica, Lair, Maris Kestrel.
Top: July sowing; bottom: June sowing.

CHAPTER XII

Bibliography

BANGA, O. (1976). Radish. In: "Evolution of Crop Plants". Ed. N.W. Simmonds. Longman Group Ltd, London. pp 60-62.

BANGA, O., PETIET, J. and VAN BENNEKOM (1965). Selecting radish for a more easily threshable silique. Euphytica. 14, 49-58.

BASTIMAN, B. (1977). ADAS work on the utilisation and use of fodder brassicae. Report of Brassica Fodder Crops Conference. Scottish Agricultural Development Council and Scottish Plant Breeding Station Publication. pp 123-132.

BASTIMAN, B. and SLADE, C.F.R. (1978). The utilisation of forage crops - a review of recent work undertaken by ADAS. ADAS Quarterly Rev. 28, 1-11.

BECKER, G. (1962). Rettich und Radies (*Raphanus sativus*). Handbuch der Pflanzenzüchtung. 6, 23-78.

BLACK, J.N. (1963). The inter-relationship of solar radiation and leaf area index in determining the rate of dry matter production of swards of subterranean clover (*Trifolium subterraneum* L.). Aust. J. agric. Res. 14, 20.

BLACKMAN, F.F. and MATTHARI, G.L.C. (1905). Experimental researches on vegetable assimilation and respiration. IV. A quantitative study of carbon dioxide and leaf temperature in natural illumination. Proc. Roy. Soc., B. 76, 402-460.

BOYD, A.G. and DICKSON, I.A. (1966). Fodder radish or rape? Agric. (London). 73, 217-222.

BRADSHAW, J.E. (1979). Kale and fodder cabbage breeding. Report of Scottish Plant Breeding Station for 1978-79, No. 58, pp 43-45.

CASTLE, M.E., FOOT, A.S., HOSKINGS, Z.I. and ROWLANDS, S.J. (1957). The yield and composition of kale and cabbage with and without nitrogenous top-dressing. J. Agric. Sci. 48, 305.

COCHRAN, W.G. and COX, G.M. (1957). Experimental Designs. London. Wiley Publications.

COCHRANE, J. and MACFARLANE, J. (1937). Marrow-stem kale. Scot. J. Agric. 20, 191.

COX, A.E. (1976). The choice of forage crops to complement grassland. Forage crops - a complement to grassland? Winter Meeting 1976 of British Grassland Society. pp 11-18.

DENT, J.W. (1963a). Digestibility tests on varieties of fodder crops in trial. J. natn. Inst. agric. Bot. 9, 395.

DENT, J.W. (1963b). The *in vitro* digestibility method - its application to the testing of varieties of fodder crops. Agric. Progr. 38, 40-49.

DIBB, C. and BROWN, A.J. (1964). Effects of date of sowing on two types of kale and one of stock-feed swedes at various harvesting dates. Expl. Husb. 11, 75-82.

DONALD, C.M. (1968). The breeding of crop ideotypes. Euphytica. 17, 385-403.

EAST OF SCOTLAND COLLEGE OF AGRICULTURE (1977). Fertiliser Recommendations (Revised Edition). Bulletin No. 18. Feb. 1977.

EAST OF SCOTLAND COLLEGE OF AGRICULTURE (1978). Time of sowing of forage crops. Report of field experiments and surveys - 1978. Part I - Crops. pp 122-126.

EVANS, G.C. (1972). The Quantitative Analysis of Plant Growth. Blackwell Scientific Publications, Oxford.

FARRAR, K. (1963). Nitrogen manuring of broadcast kale. Expl. Husb. 10, 85-96.

FRIENDS, D.J.C. (1969). *Brassica campestris* L. In: "The Induction of Flowering. Some Case Histories". Ed. LT. Evans. MacMillan, Australia. pp 364-375.

FURBER, M.J. (1978). Catch crops for autumn and winter use. Winter feed for livestock. Proceedings of the 15th NIAB Crop Conference 1978. p. 31.

GEISLER, P.A., NEWTON, J.E., SHELDRICK, R.D. and MOHAN, A.E. (1979). A model of lamb production from an autumn catch crop. Agric. Systems. 4, 49-57.

GREBINSKAYA, M.I. (1938). (The anatomy of the amphidiploid Raphanobrassica and its parents.) Bot. Zh. SSSR (Bot. J. USSR). 23, 106-121.

GREENALL, A.F. (1958). Studies on grazing of crop forages by sheep. II. Wastage of rape by grazing wethers. N.Z. J. Agric. Res. 1, 569-581.

HARBERD, D.J. (1972). A contribution to the cyto-taxonomy of *Brassica (Cruciferae)* and its allies. Botanical J. of the Linnean Soc. 65, 1-23.

HARPER, F. and COMPTON, I.J. (1980). Sowing date, harvest date and the yield of forage brassica crops. Grass and Forage Sci. 35, 147-157.

HEIDE, O.M. (1970). Seed-stalk formation and flowering in cabbage. I. Daylength, temperature and time relationships. Meldinger fra Norges Landbrakshøgrokole. 49, Nr. 27.

HIGH MOWTHORPE EXPERIMENTAL HUSBANDRY FARM (1966). Forage crops for lambs. 7th Annual Review. pp 24-25.

HOLLIDAY, R. (1960). Plant populations and crop yield: Part II. Fld Crop Abstr. 13, 247-254.

HOLLIDAY, R. (1960a). Plant population and crop yield. Nature. 186, 22-24.

HOWARD, H.W. (1938). The fertility of amphidiploids from the cross *Raphanus sativus x Brassica oleracea*. J. Genet. 36, 239-273.

HUNTER-SMITH, J. and RHYS WILLIAMS, H. (1927). A census of an acre of roots. The relation of regularity and density of plants to yield per acre. J. Min. Agric. 34, 448-455.

JOHNSTON, T.D. (1960). The effects of plant density and fertiliser on yield in marrow-stem and Canson kales. Report Welsh Plant Breeding Station 1960. pp 114-119.

JOHNSTON, T.D. (1961). Yield potential of different *B. napus* varieties. Report Welsh Plant Breeding Station 1961. pp 71.

JOHNSTON, T.D. (1962). Forage crops for extreme upland conditions. Report Welsh Plant Breeding Station 1962. pp 59-60.

JOHNSTON, T.D. (1963). The fodder radish. Report Welsh Plant Breeding Station 1963. pp 135-139.

JOHNSTON, T.D. (1971). The effect of plant density and fertiliser application on yield components in three marrow-stem kale (*Brassica oleracea* L.) varieties. J. Agric. Sci. 77, 83-89.

JOHNSTON, T.D. (1971a). A comparison of inbred lines and their F_1 hybrids in forage rape (*Brassica napus* L.). Euphytica. 20, 81-85.

JOHNSTON, T.D. (1972). Brassica crops. Report Welsh Plant Breeding Station 1972. pp 100.

JOHNSTON, T.D. (1974). Brassicae. Report Welsh Plant Breeding Station 1974. pp 30.

JOHNSTON, T.D. (1977). Breeding of improved swedes and rapes resistant to mildew and clubroot. Report of Brassica Fodder Crops Conference, Scottish Agricultural Development Council and Scottish Plant Breeding Station Publication. pp 82-88.

JONES, D.J.C. (1959). Studies of the chemical composition of kales and rapes. I. The kales. II. The rapes. J. Agric. Sci. 52, 230-243.

JONES, D.J.C. (1962). The effects of singling and advancing season on the composition of thousand-headed kale. J. Agric. Sci. 58, 265-275.

KARPECHENKO, G.D. (1924). Hybrids of *Raphanus sativus x Brassica oleracea*. J. Genet. 14, 375-396.

KARPECHENKO, G.D. (1927). Polyploid hybrids of *Raphanus sativus* L. x *Brassica oleracea* L. (in the problem of experiment species formation). Trudý prikl. Bot. Genet. Selek. 17, 389-408.

KEANE, M.G. (1974). The use of forage crops in early fat lamb production. Irish J. Agric. Res. 13, 251-262.

LAKE, J.V., FRENCH, B.K., PIKE and LEGG, B.J. (1973). Kale (Maris Kestrel). Rothamsted Experimental Station Report for 1972. pp 37.

LEACH, G.J. and WATSON, D.J. (1968). Photosynthesis in crop profiles measured by phytometers. J. appl. Ecol. 5, 381-408.

LYNCH, K. (1977). Seed production in the fodder brassicae with reference to the requirements of the United Kingdom seeds regulations for 1975-76. In Report of Brassica Fodder Crops Conference. Scottish Agricultural Development Council and Scottish Plant Breeding Station Publication. pp 89-95.

MACKAY, G.R. (1971). The brassica forages, 1970- ? Journal of the University of Newcastle-upon-Tyne Agric. Soc. 24, 16-20.

MACKAY, G.R. (1973). Interspecific hybrids between forage rape (*Brassica napus* L.) and turnip (*Brassica campestris* L., ssp. *rapifera*) as alternatives to forage rape. 1. An exploratory study with single pair crosses. Euphytica. 22, 495-499.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD (1978). Catch crops. Advisory Leaflet AG21.

McNAUGHTON, I.H. (1973). Synthesis and sterility of Raphanobrassica. Euphytica. 22, 70-88.

McNAUGHTON, I.H. (1973a). Resistance of Raphanobrassica to club-root disease. Nature. 243, 547-548.

McNAUGHTON, I.H. (1976). Evolution of Crop Plants. Ed. N.W. Simmonds. Longman Group Ltd. London. pp 53-56.

McNAUGHTON, I.H. (1977). Raphanobrassica - An inter-generic hybrid species as a club-root resistant alternative to rape. Report of Scottish Plant Breeding Station for 1976-77. No. 56. pp 34-36.

McNAUGHTON, I.H. (1978). Raphanobrassica - An inter-generic hybrid species as a club-root resistant alternative to rape. Report of Scottish Plant Breeding Station for 1977-78. No. 57. pp 36-37.

McNAUGHTON, I.H. (1979). Raphanobrassica - An inter-generic hybrid species as a club-root resistant alternative to rape. Report of Scottish Plant Breeding Station for 1978-79. No. 58. pp 49-51.

McNAUGHTON, I.H. (1980). Raphanobrassica (Radicole). Report of Scottish Plant Breeding Station for 1979-80. No. 59. pp 48-51.

McNAUGHTON, I.H. (1981). Unit for strategic brassica breeding. Report of Scottish Plant Breeding Station for 1980-81. No. 60. pp 57-60.

McNAUGHTON, I.H. and GOWERS, S. (1977). Breeding for resistance to *Plasmodiophora brassicae* (causing club-root disease). Report of Scottish Plant Breeding Station for 1976-77. No. 56. pp 36-37.

McNAUGHTON, I.H., MACFARLANE-SMITH, W.H. and ROSS, C.L. (1979). Exploitation of inter-specific crosses as possible rape substitutes or as new forage species. Report of Scottish Plant Breeding Station for 1978-79. No. 58. pp 46-48.

McNAUGHTON, I.H., MACKAY, G.R. and SNELL, C.L. (1977). Summary of research on and breeding of leafy brassicae at SPBS. Report of the Brassica Fodder Crops Conference. Scottish Agricultural Development Council and Scottish Plant Breeding Station Publication. pp 13-17.

McNAUGHTON, I.H. and ROSS, C.L. (1978). Inter-specific and inter-generic hybridisation in the brassicae with special emphasis on the improvement of forage crops. Report of Scottish Plant Breeding Station for 1977-78. No. 57. pp 75-110.

NATIONAL INSTITUTE OF AGRICULTURAL BOTANY (1980). Recommended varieties of green fodder crops, 1979/80. Farmers' Leaflet No. 2.

NATIONAL INSTITUTE FOR RESEARCH IN DAIRYING (1959). Annual Report for 1959. pp 32.

NORTH OF SCOTLAND COLLEGE OF AGRICULTURE (1978). Forage crop variety testing. (e) Co-ordinated forage brassica variety x sowing date trials, 1977. Research Investigations and Field Trials 1977-78. p. 242.

NORTH OF SCOTLAND COLLEGE OF AGRICULTURE (1979). Forage crop husbandry: co-ordinated forage brassica sowing date/utilisation date trial. Research Investigations and Field Trials 1978-79. pp 184-192.

PATERSON, W.G.W., DICKSON, I.A. and BERLYN, P. (1977). Evaluation of forage brassica crops via fattening lambs. Report of Brassica Fodder Crops Conference. Scottish Agricultural Development Council and Scottish Plant Breeding Station Publication. pp 82-88.

PEARCE, R.B., BROWN, R.H. and BLASER, R.E. (1967). Net photosynthesis of barley seedlings as influenced by leaf area index. Crop Sci. 7, 545-546.

PENDLETON, J.W., SMITH, G.E., WINTER, S.R. and JOHNSTON, T.J. (1968). Field investigations of the relationship of leaf angle in corn (*Zea mays* L.) to grain yield and apparent photosynthesis. Agron. J. 60, 422-424.

PLANT BREEDING INSTITUTE (1976). Maris Merlin marrowstem kale. Annual Report 1976. pp 143.

PLANT BREEDING INSTITUTE (1978). Condor marrowstem kale. Annual Report 1978. pp 192.

PRYTHERICH, E.I., TOULSON, G.A. and WILLEY, L.A. (1959). Kale trials 1954-57. Exp. Husb. 4, 18-27.

RADFORD, P.J. (1967). Growth analysis formulae - their use and abuse. Crop Sci. 7, 171-175.

RICHHARIA, R.H. (1937). Cytological investigations of *Raphanus sativus*, *Brassica oleracea* and their F_1 and F_2 hybrids. J. Gent. 34, 19-44.

SCOTTISH AGRICULTURAL COLLEGES (1981). Kale. Publication No. 74.

SHELDRICK, R.D., FENLON, J.S. and LAVENDER, R.H. (1981). Variation in forage yield and quality of three cruciferous catch crops grown in southern England. Grass and Forage Sci. 36, 179-187.

SHELDRICK, R.D. and YOUNG, N.E. (1977). The role of brassica catch crops in lamb production systems. Report of Brassica Fodder Crops Conference. Scottish Agricultural Development Council and Scottish Plant Breeding Station Publication. pp 111-118.

SKOLAND, N. and HILLESTAD, R. (1971). Marrowstem kale, yield and quality. Varieties, seed rates, harvesting method. Trials 1952-1968. Forskening og Forsøk i Landbruket. 22, 184-209.

SMITH, R.H. (1974). Kale poisoning. Annual Report of the Rowett Research Institute. 30, 112-131.

SNEDDON, J.L. (1962). A survey of the seed stocks of marrow stem kale and thousand head kale. J. nat. Inst. agric. Bot. 9, 154-159.

STOKES, P. and VERKERK, K. (1950). Flower formation in brussel sprouts. Meded LandbHoogesch. Wageninn. 50, 142-160.

SUGE, H. and RAPPAPORT, L. (1968). Role of gibberellins in stem elongation and flowering in radish. Pl. Physiol. 43, 1208-1214.

SZEICZ, G. (1974). Solar radiation in crop canopies. J. Appl. Ecol. 11, 1117-1156.

TAYLOR, J.P. (1977). Kale. Plant Breeding Institute Annual Report 1977. pp 97-98.

TAYLOR, J.P. (1979). Kale. Plant Breeding Institute Annual Report 1979. pp 43-44.

THOMPSON, K.F. (1958). Breeding better kales. Agric. (London). 65, 487-491.

THOMPSON, K.F. (1964). Triple-cross hybrid kale. Euphytica. 13, 173-177.

THOMPSON, K.F. (1976). Cabbages, kales, etc. In: "Evolution of Crop Plants". Ed. N.W. Simmonds. Longman Group. London. pp 49-52.

THOMPSON, K.F. and TAYLOR, J.P. (1970). Kale. Plant Breeding Institute Annual Report 1970. pp 55-56.

THOMPSON, P.B.J. and WILLCOCK, J.M. (1963). Manuring of swedes and kale in the south-west uplands. Exp. Husb. 9, 37-43.

THURLING, N. and VIJENDRA DAS, L.D. (1977). Pre-anthesis development of spring rape. Aust. J. Agric. Res. 28, 597-607.

TOOSEY, R.D. and SMITH, R.F.V. (1964). Influence of spacing and level of nitrogenous fertiliser on stem cracking and lodging in marrow stem kale. Nature. 202, 924-925.

TOOSEY, R.D. and USHER, J.W. (1966). Influence of level of nitrogenous fertiliser on the yield and dry matter content of marrow stem kale at various sowing dates. Nature. 211, 216-217.

U, N. (1935). Genome analysis in *Brassica* with special reference to the experimental formation of *B. napus* and peculiar mode fertilisation. Jap. J. Bot. 7, 389-452.

WATSON, D.J. (1956). Leaf growth in relation to crop yield. In: "The Growth of Leaves". Proceedings of the 3rd Easter School of Agricultural Science, University of Nottingham, 1956. Ed. F.L. Milthorpe. Butterworths Scientific Publications. pp 178-191.

WATSON, D.J. and FRENCH, S.A.W. (1962). An attempt to increase yield by controlling leaf area index. Ann. appl. Biol. 50, 1-10.

WATSON, D.J. and WITTS, K.J. (1959). The net assimilation rates of wild and cultivated beets. Ann. Bot. N.S. 23, 431-439.

WHITTLE, P.J., SMITH, R.H. and McINTOSH, A. (1976). Estimation of s-metylcysteine sulphoxide and its distribution among brassica forage and root crops. J. Sci. Food & Agric. 27, 633.

WILKINS, R.J. (1976). Limitations to grass for year round ruminant production. Forage crops - a complement to grassland? Papers presented at the Winter Meeting 1976. British Grassland Society. pp 1-10.

APPENDICES

APPENDIX I

Leaf Area Measurement

In order to assess the accuracy of disc sub-sampling for the determination of leaf area a comparison was made of the method, using various sizes of sample, with an alternative method employing a leaf area meter (LI-Cor Model LI-3000 Portable Area Meter from Lambda Instruments Corporation, Lincoln, Nebraska).

A ten plant sample was taken from the guard rows of each treatment plot of the 1979 sowing date x variety experiment. From each sample four leaves were chosen at random, and passed through the meter, trimming larger leaves when necessary to enable them to pass through the machine. From the remaining leaves sets of 20, 100 and 300 leaf discs were cut, using a 24 mm diameter cork borer. The fresh weight of each sub-sample was then measured and the area : weight ratio calculated. The treatment means, standard errors and coefficients of variation of each method are presented in Table 1.

The 20 disc sample had a high degree of error, producing a main plot coefficient of variance of 21%. Increasing the sample to 100 discs reduced this to 12%, and also reduced mean values by approximately 5%. Further increasing the sample to 300 discs had less effect, reducing the coefficient of variance slightly, to 11%, and not appreciably altering the mean values. The leaf area meter produced the lowest main plot coefficient of variance, at 8.7%, and the mean values were approximately 15% lower than those obtained using the disc method.

Thus the leaf area meter produced the lowest error, and was also the quickest method, appreciably so compared to sampling large numbers of leaf discs.

TABLE 1:

20 disc sample:

	Leaf Area : Weight Ratio (m^2 kg^{-1})			
	RB	L	MK	Mean
Sowing date 1	3.22	3.91	3.10	3.41
Sowing date 2	2.96	4.91	4.07	3.98
Sowing date 3	3.32	4.39	3.55	3.75
Mean	3.16	4.40	3.57	3.71

Standard error of mean, main plots (sowing date)	0.791
Standard error of mean, sub plots (variety)	0.616
Coefficient of variance, main plots	21.3%
Coefficient of variance, sub plots	16.6%

100 disc sample:

	Leaf Area : Weight Ratio (m^2 kg^{-1})			
	RB	L	MK	Mean
Sowing date 1	3.08	3.73	3.03	3.28
Sowing date 2	2.95	4.75	3.87	3.86
Sowing date 3	3.01	3.83	3.58	3.47
Mean	3.01	4.10	3.49	3.53

Standard error of mean, main plots (sowing date)	0.424
Standard error of mean, sub plots (variety)	0.462
Coefficient of variance, main plots	11.98%
Coefficient of variance, sub plots	13.04%

TABLE 1 (cont.):

300 disc sample:

	Leaf Area : Weight Ratio (m^2 kg^{-1})			
	RB	L	MK	mean
Sowing date 1	3.15	3.84	3.33	3.44
Sowing date 2	2.79	4.44	3.75	3.66
Sowing date 3	3.00	3.97	3.43	3.47
Mean	2.98	4.08	3.50	3.52

Standard error of mean, main plots (sowing date)	0.383
Standard error of mean, sub plots (variety)	0.489
Coefficient of variance, main plots	10.9%
Coefficient of variance, sub plots	13.9%

Leaf area meter:

	Leaf Area : Weight Ratio (m^2 kg^{-1})			
	RB	L	MK	Mean
Sowing date 1	2.31	3.26	3.13	2.90
Sowing date 2	2.51	3.65	2.98	3.05
Sowing date 3	2.27	3.46	3.21	2.98
Mean	2.36	3.45	3.10	2.97

Standard error of mean, main plots (sowing date)	0.258
Standard error of mean, sub plots (variety)	0.160
Coefficient of variance, main plots	8.70%
Coefficient of variance, sub plots	5.40%

TABLE 1: Leaf area : weight ratio calculated from 20, 100, 300 disc samples and leaf area meter. Treatment means, standard errors of mean and coefficients of variance.

APPENDIX II

Emergence

As density was to be an important component of the 1980 field experiment, it was decided to look more closely at the establishment of the three varieties in the field.

Tests on the performance of the drill were carried out in the laboratory, using a test-rig consisting of a fixed precision drill unit set up to deposit seeds onto a moving belt below it. The number of seeds deposited onto a 152 cm length could then be counted, giving an estimate of seed spacing.

The drill unit was set to give as close a spacing as possible, as it was in the field, by using a 144 hole No. 9 belt for the Lair and Maris Kestrel seed. Raphanobrassica had a larger seed size, and so a 144 hole No. 11 belt was used, with a larger hole size. Both should theoretically result in a seed spacing of 1.7 cm. Results for ten runs with each variety are shown in Table 1.

It was observed that the seed placing was uneven, with numerous gaps where seeds had failed to drop, plus occasional doubles, where two seeds had fallen. This partly accounts for the wider spacing, but not entirely, as even where the seed was evenly deposited the spacing was above the theoretical 1.7 cm.

In the field similar, randomly selected sets of ten 152 cm length rows were counted for the number of emerged seedlings, before singling, about a week after emergence. Results are shown in Table 2.

A larger number of double, and even triple seed placings were observed in the field than in the test runs in the laboratory. This would suggest that the drill was performing even more erratically in the more uneven conditions in the field, and that non-placement of

seeds is an important factor in the failure to gain the expected plant densities.

Thus the higher percentage figures should be taken as the more true representation of field emergence. Lair performed equally well from both sowing dates, whilst both Maris Kestrel and Raphanobrassica gave lower emergence from the July sowing. From a June sowing Maris Kestrel's emergence was equivalent to Lair, and Raphanobrassica had the lowest emergence on both dates.

TABLE 1: Laboratory test of Stanhay drill unit. Number of seeds per 152 cm test run and corresponding mean spacing for each variety.

Variety:	RB	L	MK
No. seeds per 152 cm	79	74	67
	79	71	70
	77	73	66
	76	74	68
	75	73	71
	75	73	65
	76	73	64
	75	74	61
	71	74	72
	73	73	63
Mean	75.6	73.2	66.7
Spacing (cm)	2.01	2.08	2.29

TABLE 2: Counts of emerged seedlings per 152 cm row length in the field, taken one week after emergence, and corresponding emergence %, calculated against theoretical and test drill spacings, for each variety, at each sowing date.

	Sowing Date 1			Sowing Date 2		
	RB	L	MK	RB	L	MK
No. seedlings per 152 cm	52	68	60	48	68	49
	44	70	59	53	69	54
	53	67	55	50	70	48
	66	65	54	50	63	57
	54	65	49	53	70	50
	55	62	63	45	61	55
	50	67	57	55	62	52
	49	62	58	48	60	51
	48	61	64	40	61	48
	66	60	55	50	68	57
Mean	53.7	64.7	57.4	49.2	65.2	52.1
Emergence %						
against theoretical	60	72	64	55	72	58
against test results	71	88	86	65	89	78

APPENDIX III

Weekly mean air temperatures (°C) and total rainfall (mm)

1978 week ending	Mean temp. (°C)	Total rainfall (mm)	1979 week ending	Mean temp. (°C)	Total rainfall (mm)	1980 week ending	Mean temp. (°C)	Total rainfall (mm)
3/6	15.7	0				7/6	14.7	20.5
10/6	13.2	2.4				14/6	10.7	23.9
17/6	9.9	0.5				21/6	12.6	15.3
24/6	11.1	40.0				28/6	10.9	24.6
1/7	11.9	8.8						
8/7	11.0	31.9	7/7	13.9	0.1	5/7	11.4	17.2
15/7	11.9	0	14/7	13.2	4.3	12/7	11.8	1.5
22/7	12.6	5.4	21/7	12.3	12.8	19/7	11.3	22.5
29/7	14.7	11.1	28/7	14.9	2.8	26/7	14.2	28.8
						2/8	14.5	16.1
5/8	13.6	15.0	4/8	14.4	3.9	9/8	12.9	36.3
12/8	11.9	26.3	11/8	12.8	16.2	16/8	15.5	22.3
19/8	14.4	9.9	18/8	13.5	43.0	23/8	13.0	5.2
26/8	14.0	15.7	25/8	11.2	4.2	30/8	12.9	12.1
2/9	12.1	19.9	1/9	12.3	9.5			
9/9	11.7	13.7	8/9	14.0	4.8	6/9	13.5	6.7
16/9	12.7	18.6	15/9	11.1	2.9	13/9	13.4	25.1
23/9	13.2	1.5	22/9	10.1	23.5	20/9	12.3	10.6
30/9	10.7	37.2	29/9	9.7	6.0	27/9	12.9	7.7
7/10	11.4	3.2	6/10	10.6	23.3	4/10	10.5	9.4
14/10	12.3	3.9	13/10	12.3	49.3	11/10	7.7	21.2
21/10	8.0	3.4	20/10	9.4	15.8	18/10	6.6	30.2
28/10	10.4	5.7	27/10	7.4	3.6	25/10	6.7	38.3
4/11	10.0	18.9	3/11	7.2	35.7	1/11	7.8	4.6
11/11	10.6	1.0	10/11	4.6	14.1	8/11	4.5	27.8
18/11	8.2	73.3	17/11	1.1	56.5	15/11	5.3	24.6
25/11	6.0	20.0	24/11	5.5	16.0	22/11	8.3	38.2
2/12	0.5	1.3						
9/12	3.8	26.4						
16/12	5.6	7.7						

Appendix III (cont)

	Monthly solar radiation (M.J. m^{-2})			Accumulated total		
	1978	1979	1980	1978	1979	1980
June	479	417	365			
July	390	409	335	869	826	700
August	355	360	317	1224	1186	1017
September	215	288	200	1439	1474	1217
October	156	136	149	1595	1610	1366
November	68	78	67	1651	1688	1433
December	32	43	37	1683	1731	1470